



## **Arsenic mitigation in Bangladesh**

Prepared for DANIDA

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# ARSENIC MITIGATION IN BANGLADESH

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## EXECUTIVE SUMMARY

The Arsenic calamity, which has recently hit the population of the river plains of Bangladesh and West Bengal is the largest mass exposure ever of a population to a toxic substance. The main cause for the unfortunate situation is the transformation of the traditional surface water supplies to safer sources based on the upper ground water. The Danish International Development Agency (DANIDA) has been one of the larger supporters of this transformation in order to support development and increase life quality.

In Bangladesh alone an estimated 30-35 million people are drinking water contaminated with Arsenic in excess of the present acceptable level. If the national guideline for maximum concentration of Arsenic should be lowered from 50 µg/l to the internationally recommended 10 µg/l the officially exposed number will double to approximately one third of the countrys population. The population is additionally exposed to inorganic Arsenic via food. The extent is not known but may be substantial, thus putting even further pressure on tightening the guideline for water.

The serious Arsenic related health problems are slow to appear and include cancers of internal organs, skin darkening and skin cancers, as well as gangrene of the extremities. The prevalence of Arsenicosis in affected areas is not yet high, probably as a result of the late coming of the contaminated water supplies (in the 1990's).

One of the technical difficulties has been and still is to measure and monitor the water quality in the huge number of wells (approximately 7.5 million) potentially delivering water with high Arsenic concentrations. The advent of imprecise field test kits only sorted out the grossly contaminated wells, while in the "grey" range below 100 µg/l many wrong decisions on the safety of a well may have been taken. There is not much doubt that if the field test kits continue to be imprecise and/or insensitive and expensive, a setup of laboratories throughout the country using instrumental methods should be preferred,

In an attempt to control the situation the Bangladesh government has entered into co-operation with several international organisations to device proper mitigation measures. The present major discussion is on the available and realistic options for securing a long term situation with lowering the human exposure to acceptable levels.

The first option is to develop further the methods for the hygienisation of the Arsenic free, but unsafe surface waters. This may be achieved by conventional and well known methods like slow sand filters or infiltration galleries near to open water bodies like ponds, rivers and dug wells. The techniques behind are simple, although not cheap, and requires running maintenance. These methods also require a fair amount of public interest and participation in order to be long-term solutions. Rainwater harvesting as an alternative option for drinking water is not practically feasible with the present situation of thatched roofs.

The second option is to develop the methods for removal of Arsenic from the upper ground water presently constituting the bulk supply of drinking water to the rural population. These options will have to be implemented on a household basis or in smaller community based units and will require

a genuine public participation in operation and maintenance. Still the operation of fitting an estimated 7.5 million tube wells with some sort of treatment seems equally unsurmountable.

The third option apparently preferred by the donor organisations is to utilise the very deep groundwaters (> 150m) of the delta regions. This is an attractive option, but also an expensive and risky undertaking. The deeper ground waters are old and may not be replenished by uncontaminated water, and thus grow salty or become Arsenic contaminated from above. As the installation is slow and fairly costly the number of families connected to one deep tube well has to be higher than for other options in the rural areas. The sheer size of the operation to provide water to the population at risk seems large and lengthy.

The above options are not listed according to feasibility.

If the task is on a regional scale quickly to implement safe water supplies to the maximum number of people, the preferred way may be to support the local and accepted methods. That points at a combination of possibilities:

In locations with abundance of Arsenic free surface water to revert to hygienisation of the water at the household level.

In locations with many shallow tube wells to screen the Arsenic concentrations, and to advice on the available methods to treat or to avoid the contaminated water by changing the source for drinking purposes alone.

In locations with already installed deep tube wells to effectively and reliably monitor the quality of the water on a regular basis e.g. with a frequency of 2-5 years for selected tubewells at risk of contamination. To secure the long term exploitation of the deep ground waters it should be reserved for drinking water purpose, and mechanical large scale pumping be avoided.

To assure that whatever chosen combination of solutions for the rural areas is the best and of reasonable sustainability, the human capacity building should be of very high priority to the Bangladesh government and to the donor organisations. This points to mass education of professionals at each required level, from vocational and technical schools to universities.

The research and development needs of Bangladesh in the water supply field apparently are not very well anchored with nationals. In the longer term the collaboration to foreign universities could be more formalised, and be an integrated part of the water and sanitation support.

## Abbreviations:

AAHG	Atomic Absorption Hydride Generation
AAS	Atomic Absorption Spectrometer
AIHH&H	All India Institute of Hygiene and Public Health
AMC	Arsenic Mitigation Component
AMPP	Arsenic Mitigation Pilot Project
APSU	Arsenic Policy Support Unit
As	Arsenic
ASS	Assumed by Appraisal Team
BAMWSP	Bangladesh Arsenic Mitigation Water Supply Project
BCSIR	Bangladesh Council of Scientific and Industrial Research
BGS	British Geological Survey
BRAC	Bangladesh Rural Advancement Council
BTU	Bucket Treatment Unit
BUET	Bangladesh University of Engineering and Technology
DANIDA	Danish International Development Agency
DCH	Dhaka Community Hospital
DHTW	Deep Hand Tube Well
DPHE	Department of Public Health and Engineering
DTU	Technical University of Denmark
F&D	Fill and Draw Unit
GOB	Government of Bangladesh
IRU	Iron Removal Unit
LGE	Local Government Entity
LUCED	Linked University Consortia for Environmental and Development
MCL	Maximum Concentration Level
NAMP	National Arsenic Mitigation Program
NGO	Non Governmental Organisation
NIPSOM	National Institute of Preventive and Social Medicine
PHED	Public Health Engineering Department
PSF	Pond Sand Filter
R&D	Research and Development
Rs	Rupees (Indian Currency)
SDDC	Silver Diethyl DithioCabamate
SHTW	Shallow Hand Tube Well
SOES	School of Environmental Science
SORAS	Solar Oxidation and Removal of Arsenic
SPS	Sector Programme Support
Tk	Taka (Bangladeshi Currency)
TW	Tubewell
UNICEF	United Nations Children's Fund
WHO	World Health Organisation
WSS	Water Supply and Sanitation
ZPC	Zero Point of Charge

## BACKGROUND

In recent years, elevated concentrations of Arsenic (As) in ground waters of Bangladesh and other areas in the delta plains of the Brahmaputra and Ganges came to light in certain areas. The consequences of this natural contamination is that ground water from many shallow hand tube wells has high As concentrations, often far above accepted quality guidelines. This has led to high incidences of chronic As poisoning (Arsenicosis) in the affected regions. The WHO recommends a maximum acceptable concentration of 10 µg/l. Bangladeshi authorities have established a national limit of 50 µg/l. Numerous shallow hand tube wells (SHTW) have been closed, because the concentration of Arsenic in the pumped water exceeds this limit.

Alternative water sources and different water cleaning techniques have been studied extensively (also under different components of the present DANIDA SPS). A comprehensive documentation is available on hydro-geological issues, health issues, alternative water supply options, and water cleaning techniques. However, no clear picture exists of possible solutions to the serious Arsenic problem in Bangladesh.

Under the DANIDA funded Arsenic mitigation component the solution adopted is the construction of deep hand tube wells (DHTW) in affected areas in the Coastal Belt. Also under the rural water supply component, thousands of DHTWs are presently being financed, partly by DANIDA and partly by the Government of Bangladesh. This choice of water supply source is based on the fact that, so far, Arsenic has not been detected at high concentrations in the ground water of the deeper aquifers. Nonetheless, no reliable scientific evidence has been provided so far that Arsenic will not occur at a later stage in these aquifers.

No regular ground water quality monitoring takes place at present at point sources in Bangladesh. DANIDA performs initial screening analyses of new DHTWs in order to verify the water quality. However, imprecise and insensitive field test kits or equally insensitive laboratory methods with detection limits from 10 to 50 µg/l or higher are applied, so only a few reliable quantitative analyses are performed at concentrations around the recommended concentration limits.

During the joint annual sector review in January 2002, it was decided to finance a comprehensive ground water quality monitoring programme in the Coastal Region. However, this activity has apparently been delayed due to lack of analytical capacity for quantitative, trace-level analysis of Arsenic in Bangladesh, and due to a wish to harmonise and coordinate the approach with that of the much delayed, nation-wide monitoring programme, known as BAMWSP, which is supported by the Bangladeshi authorities.

At this basis, some doubts remain regarding the best approach to adopt for Arsenic mitigation in Bangladesh. Thematic discussions on this issue, including its health implications, will take place during the joint annual sector review in February 2003.



## INTRODUCTION

Countries like Bangladesh (BGS 1999), and India (West Bengal) (Chatterjee et al. 1995) are facing major drinking water problems due to elevated concentrations of Arsenic in pumped ground water. Incidences of elevated Arsenic concentrations have also been reported from Argentina (Nicolli, H.B. et al., 1989), Chile (Briggs M. L, 1988), Mexico (Del Razo et al., 1990), Taiwan (Tseng et al., 1968), USA (Sonderegger & Ohguchi, 1988, Korte N., 1991, Welch et al., 1988), Vietnam (Berg et al., 2001). The problem in the Ganges delta (Bangladesh and India) is by far the largest with approximately 40 million people potentially exposed to Arsenic concentrations of 0-3200 µg/l (DPHE/BGS/MML, 1999, Smidley & Kinniburgh, 2002).

### ***ARSENIC AND WATER IN BANGLADESH***

Since the discovery of the Arsenic contamination of water in 1993, the magnitude of Arsenic contaminated shallow hand tube wells (SHTWs) has increased drastically, with an estimation of a possibility of approximately 25% of the 7.5 million shallow tube wells (total number of tube wells in Bangladesh estimated by WHO Ahmed M.F., 2002), with 30-35 million people (BGS,DPHE 2001) at risk of consuming Arsenic contaminated drinking water. Before the installation of shallow tube wells, people in Bangladesh were using surface water as a source of drinking water and were suffering from diseases like diarrhoea due to the bacteriological contamination of the surface water. Since the 1960's the WHO and other agencies have advocated ground water as an alternative source of drinking water. The water was not tested for Arsenic because there was no prior studies showing that ground water could be contaminated with Arsenic. Even though the first digging of shallow tube wells took place by the donor agencies in the 1960's the numbers of tube wells sunk were very few until the 1990's when the number increased exponentially, as the number of privately owned tube wells increased in these years. Figure 1 shows the map of Bangladesh and Figure 2 shows the distribution of Arsenic in Bangladesh. Figure 3 show the number of tube wells installed in different years, the data is taken from the BGS database, where around 3500 tube wells from Bangladesh were tested for their Arsenic concentration.

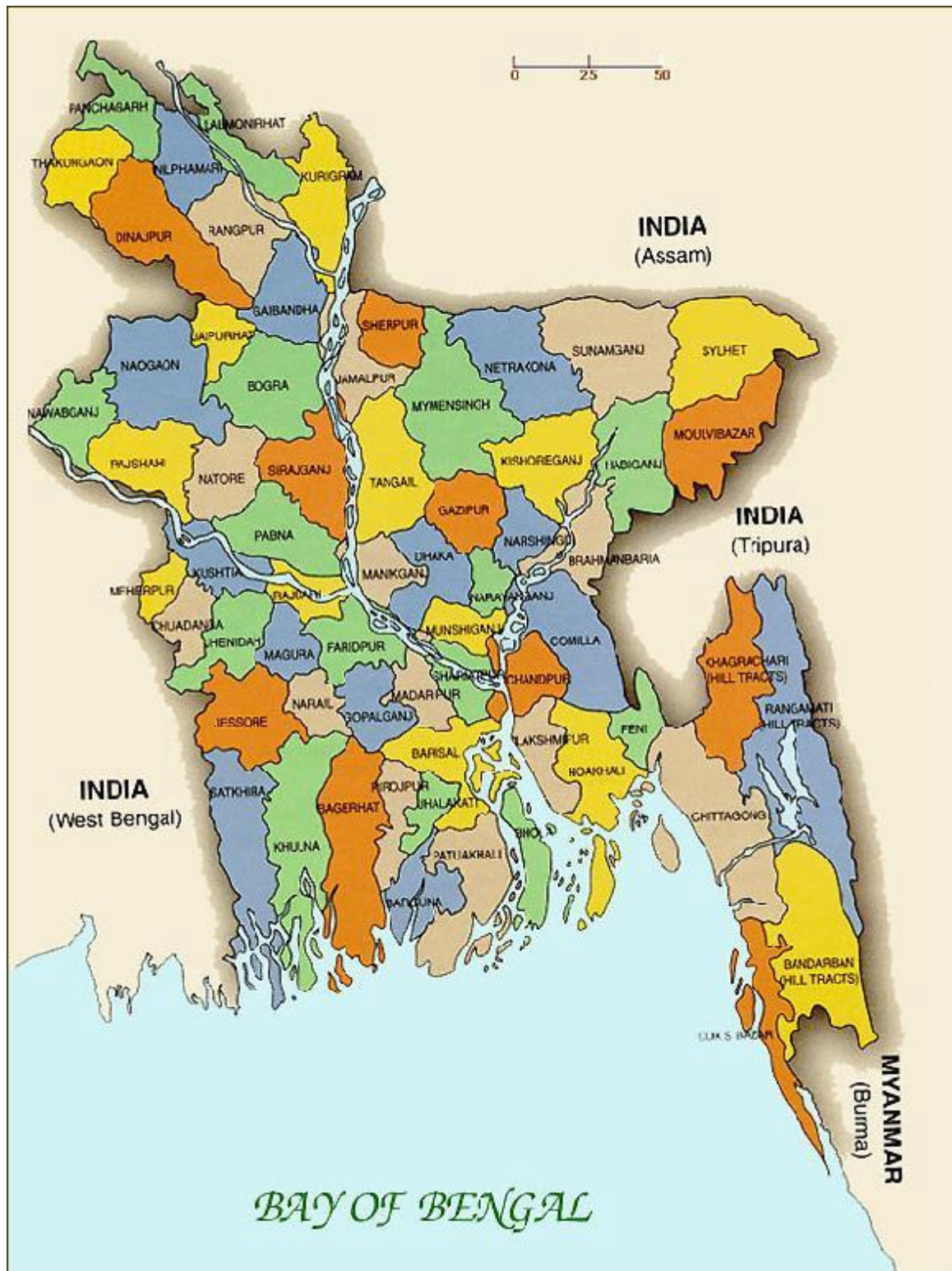


Figure 1: Map of Bangladesh

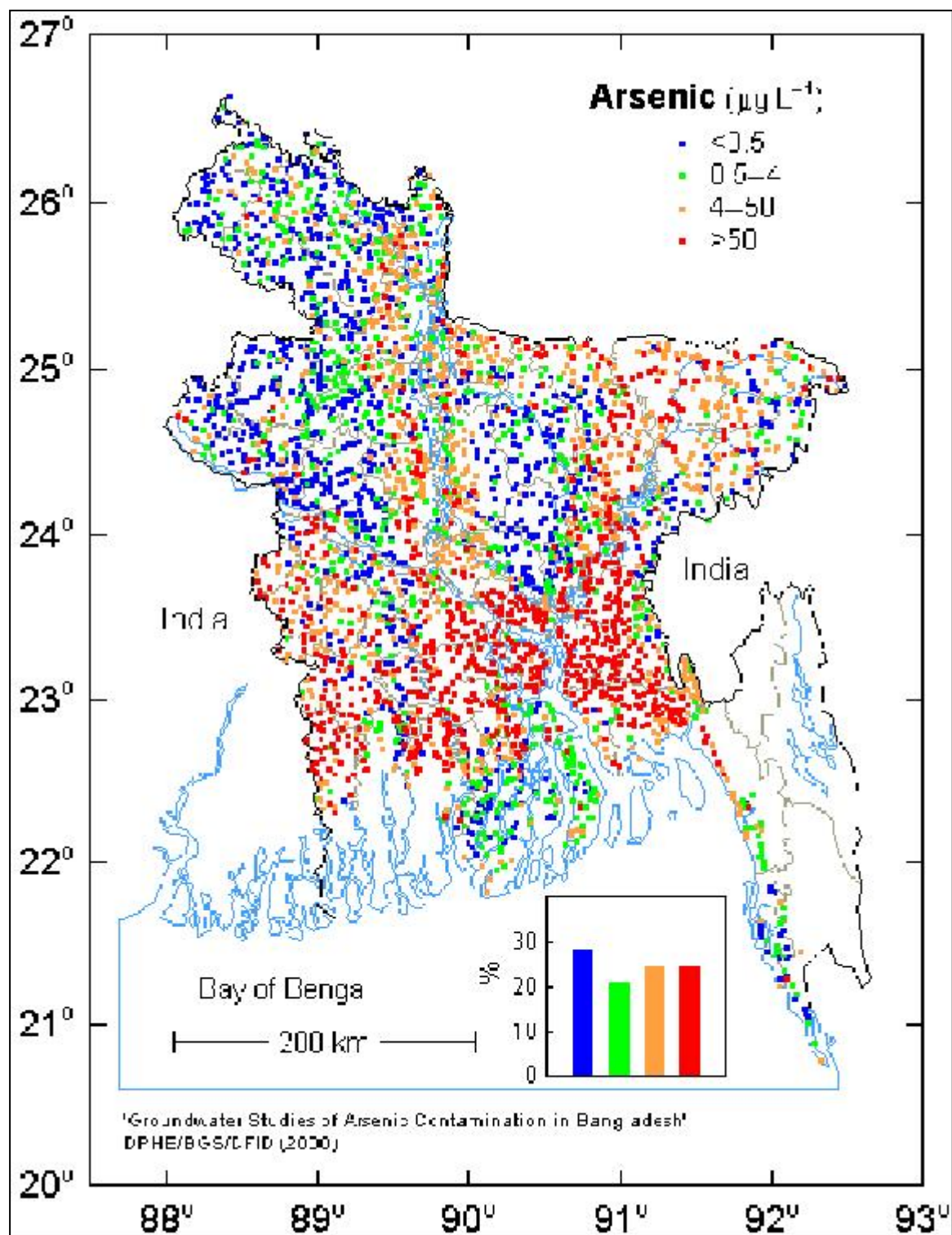


Figure 2: Distribution of Arsenic in Bangladesh. (Taken from the BGS website: [www.bgs.ac.uk](http://www.bgs.ac.uk))

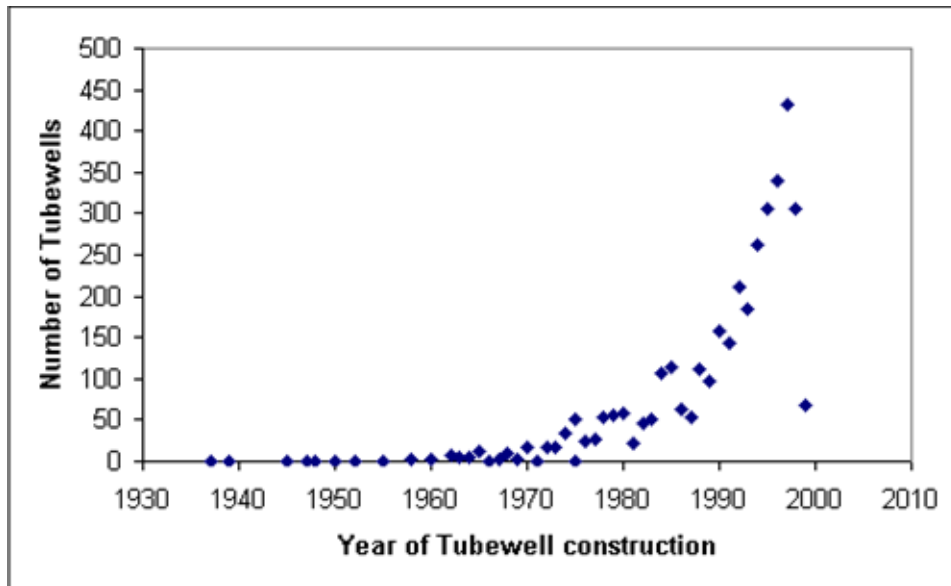


Figure 3: Comparison of number of tube wells installed in each year. The number of tube wells on the Y-axis indicates the number of tube wells tested by BGS that were installed in a particular year: (Data from BGS)

It is tragic to see that so many tube wells were installed despite of the knowledge of the Arsenic in the ground water. Geen et al. 2001, also reported a roughly doubling of the number of tube wells every 5 years in the studied area of Araihasar Upazila. The figure shows that even in year 1999 there are many tube wells installed. The BGS surveyed 69 tube wells constructed in 1999, of which 12% contain Arsenic concentration above 50  $\mu\text{g/l}$  (Bangladesh standard) and 35% contained Arsenic concentration above 10  $\mu\text{g/l}$  (the WHO standard).

## ***PUBLIC AWARENESS OF THE PROBLEM***

The survey conducted by the Arsenic Mitigation Pilot Project of DPHE-DANIDA (AMPP), which started in March 1999 in the areas of Choumohani and Laksmipur, showed that more than 50% of the population did not have any knowledge on Arsenic contamination, and that more than 85% of the people did not know about the health implications by ingestion of Arsenic (Mahalder, Khan and Paus 2002, Arsenic Mitigation Pilot Project 1999-2001). The studies (Parvez et. al., 2001; Caldwell et. al., 2002) by others show that in the areas, where various agencies have Arsenic mitigation projects the awareness about Arsenic contamination is high, but still the awareness about the serious health implication with consumption of Arsenic contaminated water is very low. In a controlled area where there is no Arsenic mitigation projects the awareness among people on Arsenic contamination is even lower.

Although people are aware of the Arsenic contamination, they still use the Arsenic contaminated ground water, because there is no other suitable source of drinking water. The field experience show that people believe that Arsenic can be removed by boiling the water; therefore some people use boiled water for drinking. For the same reason many people use Arsenic contaminated water for cooking purpose.

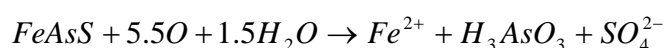
## **ARSENIC CHEMISTRY AND MOBILISATION INTO WATER**

Arsenic being the 20<sup>th</sup> most abundant element in the Earth's crust (approximately 2-5 mg/kg) (Viraraghavan et al., 1994), occurs naturally in most of the reported incidences of water contamination. The theories that have been put forward to explain the origin of Arsenic in water, points at both anthropogenic and natural causes.

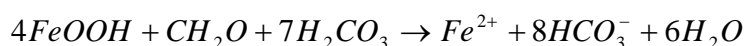
The anthropogenic contamination is due to the use of fertilizers, pesticides, insecticides, waste disposal, Arsenic treated wooden poles etc. This theory was ruled out for groundwater by many scientists, since contamination of Arsenic in the proportion as it is in Bangladesh is not possible due to the anthropogenic sources and also the Arsenic concentration in the top soil layer is less.

There are two hypotheses trying to explain the mechanism for Arsenic release from the natural sources: Pyrite oxidation hypothesis and Oxyhydroxide reduction hypothesis.

Pyrite oxidation hypothesis: This theory was put forward by the scientists from School of Environmental Sciences, Jadavpur University, West Bengal India. According to this hypothesis Arsenic is released to the ground water due to the oxidation of Arsenic rich Pyrite (FeS) and Arsenopyrite (FeAsS) . When ground water table is lowered due to pumping oxygen is penetrating in to the aquifer and oxidises Pyrite and releases Arsenic according to the following equation.



Oxyhydroxide reduction hypothesis: This hypothesis was put forward by Nickson et al. 1998 based on the data from Bangladesh. According to this hypothesis the release of Arsenic to ground water is through reduction of arseniferous Iron-oxyhydroxides under anoxic conditions during sediment burial. The process dissolves Fe oxyhydroxide and releases to ground water both  $Fe^{2+}$  and the sorbed ions of the Fe-oxyhydroxide including As.



Scientists around the world are trying to explain the possible Arsenic contamination in Bangladesh based on the above 2 theories.

Arsenic is present as inorganic Arsenic in the ground waters and may occur in the oxidation states +3 (Arsenite) and +5 (Arsenate). Only Arsenate is present as oxyanion in the neutral pH range. The pKa values of Arsenic Acid (As(V)) are 2.2, 7.1 and 11.5, whereas for Arsenous acid (As(III)) they are 9.2, 12.3, and 13.4. Even though As(III) is more predominant under reducing conditions and (As(V)) is more predominant under oxidising conditions, both species can occur in both conditions depending on the environmental circumstances. For example, the reduction of As(V) to As(III) is very slow, resulting in presence of As(V) in reducing environments. Moreover low steady-state concentrations of As(III) in oxic waters may be maintained by biological reduction of As(V) (Edwards 1994). The non-ionic nature of the Arsenite makes it much less prone to precipitation and adsorption reactions than Arsenate.



## ***THE HYDROLOGY***

In Bangladesh the aquifers are divided into three groups depending on their vertical distribution, these are upper Aquifer, main aquifer (50-150m deep) and lower aquifer. The upper aquifer is thin in NW Bangladesh and is as thick as 60 m in the south. There is a silty/clay layer with variable thickness on the top of the upper aquifer. The main aquifer-containing medium to coarse sand with discontinuous thin clay layers lies beneath the upper aquifer, and most of the deep tube wells are withdrawing water from this aquifer. Depth of this aquifer depends on the geological nature of the particular area. These two aquifers are separated by thin multi-layered discontinuous clay and may be termed as leaky aquifers. Ground water of the upper and main aquifers is affected by Arsenic contamination in most part of the country. The lower aquifer (deep aquifer) lies beneath the main aquifer and is separated from the main aquifer by a thick clay layer. The thickness and depth of the lower aquifer depends on the geological nature of the area. Generally the depth of the lower aquifer is considered 200 m below the ground level. In the coastal belt this aquifer lies in the range of 210-300m, and in the red soil area this aquifer is in the range of 150-460m deep. The water from this aquifer is 20,000+ years old.

It is confusing to divide the aquifers as above since the thickness of each layer can vary, therefore it is logical to divide the aquifers in the geological point of view as follows:

- Late Pleistocene-Holocene aquifers
  - Upper Holocene aquifers
  - Middle Holocene aquifers
  - Lower Holocene aquifers
- Plio-Pleistocene aquifers

The Pleistocene upland covers about 10% of the country. Plio-Pleistocene Dupi Tila sandstone, which is also classified as deep aquifer lies below a thick silty clay layer of Pleistocene age. Dhaka city is withdrawing its water from this aquifer and this aquifer is reported to be free from Arsenic.

The Late Pleistocene-Holocene aquifers lay above the Pleistocene clay and the thickness of these deposits is highly variable. This aquifer is divided into 3 parts. The lower Holocene aquifers are free from Arsenic. Most of the shallow tube wells withdraw the water from the middle Holocene and upper Holocene aquifer and these aquifers are contaminated with Arsenic. The upper Holocene aquifer is not present in all the deltaic and flood plain areas. In the coastal part the Holocene aquifers are affected by saline water (Arsenic Mitigation in Bangladesh 2002).

According to the review by Smedley & Kinniburgh 2001 the affected aquifers are generally shallow (100-150 m deep) of Holocene age with deposits of Ganges, Brahmaputra and Meghna river systems. This literature review also shows that the reasons for the distinction between ground water As concentrations in the shallow and deep aquifers of the Bengal Basin are not well-understood.

## **HUMAN EXPOSURE AND RISK ASSESSMENT**

This chapter will present the possible routes of exposure to Arsenic, the risks associated with drinking Arsenic contaminated water and discuss about the established guideline values.

## ***ROUTES OF HUMAN EXPOSURE:***

The routes of Human exposure to Arsenic can be through food, water and air. The general values of exposure through air, water and food are shown in Table 1 (Vahter, 1994).

Source	Inorganic Arsenic ( $\mu\text{g/d,p}$ )	Organic Arsenic compounds ( $\mu\text{g/d}$ )
Air	0.05	-
Food	5-20	5-1000
Water	<1-10	-
Smoking	1-20	-

Table 1: Intake of inorganic and organic Arsenic compounds in the general population.

*Air:* Normally the concentrations of Arsenic in air are in the range of  $0.4\text{-}30 \times 10^{-3} \mu\text{g As/m}^3$  (WHO, vol.2, 1996). 30-85% of the inhaled Arsenic can be absorbed and USEPA has estimated that the general public's intake of Arsenic would be in the range of 0.04-0.09  $\mu\text{g/d}$  (Pontius et al, 1994). People living near smelters, power plants using coal and oil with high Arsenic concentrations, and households using coal with high concentrations of Arsenic can get exposed to Arsenic concentrations as high as  $1 \mu\text{g/m}^3$  resulting in a real intake of 6-17  $\mu\text{g/d}$  (assuming that an adult inhales  $20 \text{ m}^3$  of air per day). Liu et al., 2002 reported an incidence of extreme indoor air Arsenic concentrations in the range of  $20\text{-}400 \mu\text{g/m}^3$  in China, where people used coal with high Arsenic concentration for preparation of food raising the Arsenic intake tremendously.

*Food:* The Arsenic intake through food is widely varied depending on the type of food consumption. Based on the market basket survey of total Arsenic the US food and Drug administration has estimated that adults ingest on average about 53  $\mu\text{g As/d}$  from the diet (Pontius et al., 1994). A Japanese study showed a daily intake of Arsenic at 182  $\mu\text{g}$ , which is very high, compared to other studies, and is largely attributed to the consumption of seafood by Japanese. In a Dutch study the daily intake of total Arsenic range between < 5 to 950  $\mu\text{g/d}$ . According to WHO the mean daily intake of Arsenic through food by adults is in the range of 17-129  $\mu\text{g}$  (WHO, vol.2., 1996). Generally it is only the inorganic Arsenic, which is considered toxic to humans, while the organic forms appear virtually non-toxic. The content of inorganic Arsenic in food can vary from 5%-100% of the total Arsenic in food, for example in vegetable it is around 5%, whereas in meat and milk products it can be 75% (Pontius F.W. et al. 1994).

*Water:* Arsenic concentration in most natural waters generally varies between 1-2  $\mu\text{g/l}$  resulting in an Arsenic intake of 2-4  $\mu\text{g/d}$  assuming that an adult consumes 2 l of water per day (WHO, vol 2. 1996). This value is very low compared to the exposure through food.

A study conducted in West Bengal, India (Roychowdhury et al. 2000) estimated that the average intake of drinking water per day for adult male is 4 l and for females it is 3 l. With a mean Arsenic concentration of 133  $\mu\text{g/l}$  in drinking water in one of the studied blocks the study found that the average daily intake of Arsenic from drinking water by an adult is 532  $\mu\text{g}$  and the average intake of inorganic Arsenic through food is 86  $\mu\text{g/d}$  (assuming that 50% of total Arsenic in food is inorganic

Arsenic). In this case the inorganic Arsenic intake through food accounted for around 14% of the total Inorganic Arsenic intake.

The importance of the various routes of exposure to Arsenic depends on the actual concentration. Usually in places where the Arsenic concentration in the ground water is less (1 µg/l) and no pollution of air due to industries, the major route of exposure to Arsenic would be through food. But in Bangladesh and India where the Arsenic concentration in the ground water can be up to 3200 µg/l with a water consumption of 3.5 l, the intake through drinking water will be much higher than the intake through food.

### ***HEALTH EFFECTS:***

Arsenic is a known carcinogen and incidences of populations suffering from Blackfoot disease due to long term exposure to Arsenic concentrations (0.1-1.8 mg/l) are reported in the literature (Tseng et al., 1968). The most common symptoms of long-term low level Arsenic exposure are variations in skin pigments, hyperkeratosis, and ulcerations. There is documentation that Arsenic can cause kidney, bladder, skin, lung, and liver cancer.

The Arsenic related health effect, commonly known as Arsenicosis maybe divided into four stages Pre-clinical, clinical, complication and malignancy (Mandal, et. al. 1996).

1. Pre-clinical stage: This may be divided into
  - Chemical phase. Urine showing Arsenic excretion during intake of ground water containing higher Arsenic concentration;
  - Sub-clinical or occult phase: Body tissues showing high Arsenic concentrations with no apparent clinical symptoms.
2. Clinical stage: The presence of clinical symptoms is confirmed by detection of higher Arsenic concentration in nail, hair, and skin scales.
3. Stage of complication: Symptoms of clinical phase are associated with different complications as the organs like lung, liver, muscles, eye, vessels are affected.
4. Stage of malignancy: Malignancy affecting skin, lung, bladder, or other organs develops if patient survives the stage of complications.

The signs and symptoms of Arsenicosis are as follows (Arsenic Mitigation in Bangladesh 2002):

- Common dermatological manifestations: pigmentary changes in skin and/or mucous membrane, hyperkeratosis
- Common non-dermatological manifestation: weakness, conjunctivitis, respiratory illnesses, peripheral neuropathy like numbness
- Problematic and serious manifestations: gangrene, chronic ulcers, Bowen's disease, squamous cell carcinoma, basal cell carcinoma, adverse pregnancy outcomes, cancer of internal organs (lungs, bladder, kidney), skin cancer, diabetes, hypertension.



Literature review shows that the Arsenic related health effects in the early stages can be cured if people drink Arsenic free water and the only way to prevent the progress of the disease is to stop drinking Arsenic contaminated water. There is also evidence that providing patients with vitamins, especially Vitamin A, C, E and enriched diet aids recovery. Symptoms such as skin hardening can be treatable with simple skin ointments.

## ***RISK ASSESSMENT AND SETTING GUIDELINES***

The quantitative Arsenic intakes causing the above symptoms are yet not entirely known. The health effects of Arsenic seems to vary a lot for each individual depending on genetic conditions, nutrition level, amount of exposure, duration of exposure etc (Viraraghavan et al., 1994, Pontius et al., 1994, Brown & Chen 1995).

When comparing studies several factors may influence the results. One observation is that between the studies showing correlation for cancer incidence, this appears to be at high concentrations compared to the studies without correlation, where Arsenic concentrations in drinking water were lower. Another observation is that the exposed groups with correlation are from developing countries with poor nutritional state, whereas the exposed groups without correlation are from industrialised countries with good nutritional diet. A third observation is that the studies with cancer correlation are from villages, where usually most of the dietary products consumed are produced in the village, probably using highly Arsenic contaminated water for drinking and irrigating plant growth. A study shows (Schoof et al. 1998) that the food products grown in Taiwan contained high amounts of Arsenic. This indicates that the Arsenic through food products also contributed to the high incidence of skin cancer in the Tseng et al., 1968 study. According to Tsuda et al., 1995 there is synergism between ingested Arsenic through drinking water ( $> 50 \mu\text{g/l}$ ) and smoking in developing lung cancer in an exposed population in Japan.

Usually when establishing a guideline value for maximum intake of a substance, results from animal studies are extrapolated to define the guideline values. In case of Arsenic until so far no animal studies are available that show for certain that exposure to Arsenic causes skin and other internal cancers. On the other hand there are studies where evidence of cancer among human with exposure to high levels of Arsenic is available. The studies are from Taiwan, Argentina, Mexico (Cebrian et al., 1983), India (Mazumder G. D.N., 2001) and Bangladesh (Rahman & Axelson., 2001; Ahsan. et al., 2000). One of such studies from Taiwan is the extensive work done by Tseng et al in 1966, where the authors collected data on the exposure to Arsenic and prevalence of skin cancer in a population of 40,421 in Taiwan. The study showed that there were 428 cases of skin lesions among the studied population and there were no reported cases of skin lesions for people under the age of 20 years. Prevalence rate increased with an increase in age. Higher skin cancer rate was reported in males compared to females, whereas there was no difference between the sexes when hyper pigmentation and keratosis were taken into consideration.

However, there are studies, which show that at lower exposure levels there was no excess risk of getting cancer. These studies are from the Oregon, Utah Study (Lewis et al., 1999), Belgium, and Finland. The study from Utah showed that there was no observed excess incidence of death due to cancer and high Arsenic concentrations in drinking water. The Arsenic concentrations in the water ranged between 14-166  $\mu\text{g/l}$ .

The estimated life time risk of getting skin cancer from drinking water at the WHO's provisional guideline value of 10 µg/l is  $6 \times 10^{-4}$ . According to et al. 1992, the excess risk of dying due to internal cancer (bladder, liver, kidney cancer) at the 50 µg/l is  $1 \times 10^{-2}$ , which at 10 µg/l would be  $2 \times 10^{-3}$  assuming a linear response to intake, which is much higher than the risk due to skin cancer. In usual practise when setting a guideline value for intake of a toxic compound, a risk of  $10^{-6}$  is accepted. But in case of Arsenic a much higher risk is apparently accepted.

The above-calculated risks are based on an American population with an average body weight of 70 kg and daily water consumption of 2 l. In case of Bangladesh the average body weight is around 52.5 kg (In most of the studies from Bangladesh the average body weight was 50 kg) and the daily water consumption is 3-4 l. A guideline value can be calculated using the following formula.

$$GV = (TDI \cdot bw \cdot p) / C$$

Where:

GV = Guideline value; TDI = Allowable Concentration of the substance (µg/bw,day) ;bw = Body weight; P = fraction of the TDI allocated to drinking water; C = daily water consumption.

If we assume that 100% of Arsenic is consumed through drinking water and the daily water consumption of a Bangladeshi is 3.5 l then the guideline value for a Bangladeshi giving the same risk (TDI) as for an American at 50 µg/l and 10 µg/l would be 23 µg/l and 4 µg/l. The maximum concentration level allowed in Bangladesh is 50 µg/l and the Arsenic mitigation work in Bangladesh is also focussing on supplying drinking water with less than 50 µg/l.

## ***IS ARSENIC IN FOOD A SIGNIFICANT RISK?***

As mentioned earlier, the inorganic Arsenic consumption through food in the studied areas of West Bengal was 86 µg/d. The study also contains a list on the Arsenic concentration in various food products. A study (Schoof et al. 1998) from Taiwan with elevated Arsenic concentrations also showed that Sweet Potatoes were grown in the Arsenic contaminated area contained elevated concentration of Arsenic.

A study (Jiang & Singh 1994) on effect of different forms and sources of Arsenic on crop yield and Arsenic concentration showed that both Arsenate (As(V)) and Arsenite (As(III)) significantly decreased the yields of ryegrass and barley and that there was a marked difference between the response of the two plants. Arsenic concentration in the crops increased with an increase in the application rate. Arsenic concentration in barley straw was much higher than the Arsenic concentration in the barley grain. The different parts of plants accumulate varied levels of Arsenic in tissues, with highest residues of Arsenic in roots, intermediate values in vegetative parts, and edible seeds and fruits containing the lowest values. The application of phosphatic fertilizers with high concentrations of Arsenic has also an effect on the intake of Arsenic by the plant.

A study by D'Ilio et al 2002 showed that the content of Arsenic in 8 varieties of unprocessed rice grown in North Italy varied from 80-208 µg/kg depending on the rice varieties. A study conducted in Bangladesh (Abedin Md. Joinal et al. 2002), where rice plants were grown in the laboratory with different Arsenic concentrations in irrigation water showed that Arsenic can be accumulated in the

plant and rice with the accumulation sequence of root>straw>husk>grain, but the study did not show any increase in the Arsenic concentration in the rice grain with an increase in the Arsenic concentration in the irrigation water.

If it is assumed that the amount of Arsenic intake in the food for a Bangladeshi is the same as the Arsenic intake in the studied area of West Bengal, then the inorganic Arsenic intake through food would account for 33% of the total inorganic Arsenic intake at the Bangladeshi standard of 50 µg/l and 3.5 l water intake per person per day. At the WHO guideline value of 10 µg/l the inorganic Arsenic intake through food would be 71%. These results indicate that the inorganic Arsenic intake also plays a major role in the exposure to Arsenic concentration at lower water Arsenic concentrations. These calculations are based on a single study and on the assumption that 50% of the total Arsenic through food is in the inorganic form. This assumption could be an overestimation. According to Pontius et al. 1994, the inorganic Arsenic content in rice is 35%, and in vegetables it is 5-10%, whereas in meat and milk products the inorganic Arsenic content is 75%. The main food of the rural population of Bangladesh is rice and vegetables and if this is true then the inorganic Arsenic concentration in the food will be less than 50%. There could be other differences between the studied population and the population in Bangladesh like the rice variety. Therefore further study is needed to quantify the amount of Arsenic intake through food.

## **SUPPLY OF ARSENIC FREE DRINKING WATER**

The demand for Arsenic free drinking water can be met by finding alternative sources of drinking water free from Arsenic and/or treating the Arsenic contaminated water. This chapter contains the different possible ways of supplying Arsenic free water and the advantages and disadvantages of each possibility (Arsenic Mitigation in Bangladesh, 2002).

### ***SUPPLY FROM RAIN WATER HARVESTING:***

Rain water harvesting could be an option to supply Arsenic free drinking water and was implemented on trial basis in some places. In one of the experiments faecal coliform bacteria were observed in 26 out of 162 rainwater storage tanks. In another experiment the tank had dried out when the water was to be used. This technology has never been used in Bangladesh, but is widely in use in other East-Asian countries with some success. A disadvantage of implementing this technology in rural areas is that thatched roofs are not good for rainwater harvesting and that infection risk from bird droppings is real. These drawbacks may be minimised on hard roofed buildings, but the stored water should be treated before use as drinking water (An Action plan for Arsenic Mitigation with Danish Sector Program Support, 2001).

### ***SUPPLY FROM SURFACE WATERS:***

Bangladesh has an abundance of surface water in the form of ponds, lakes and slow flowing rivers. The water supply was solely based on surface water before the introduction of ground water. Surface water cannot be utilised directly from the source without treatment due to substantial infection risk. Pond sand filters are usually used for treatment of surface water, but have not gained popularity among the population due to aesthetic and safety reason, but is accepted for cooking.

Infiltration galleries or wells can be constructed near rivers or ponds to collect infiltrated surface water for all domestic purpose. Thus minimising the infection risk and removing unaesthetic particulate matters.

## ***SUPPLY FROM GROUND WATER:***

### **Dug well (open wells without protection):**

Studies show that Arsenic concentration in most of the dug wells is very low probably due to continuous oxidising conditions and Iron precipitation. Before the installation of tube wells dug wells have been used as drinking water source. The problem with dug wells is that it is very difficult to protect the water of the dug well from bacterial contamination. Water in the well should be regularly chlorinated for disinfection or treated in other ways before use for drinking purposes.

### **Shallow shrouded tube well and very shallow shrouded tube well (bore holes utilising the very upper layers of water in the soil/sediment):**

In many areas, ground water with low Arsenic content is available in shallow aquifers composed of fine sand and shallow depth. This may be due to accumulation of rainwater in the topmost aquifer or dilution of Arsenic contaminated ground water by fresh water recharging every year from surface and rainwaters. To get water through the very fine-grained aquifers, artificial sand packing is required around the screen of the tube well. DPHE has sunk these tube wells in coastal areas to provide safe water. The infection risk is much reduced and other treatment may not be necessary.

### **Shallow tube well (bore hole utilising the upper part of the primary ground water):**

The shallow tube wells are sunk into the lower part of the upper aquifer to ensure stable supply of water. The redox conditions at this depth are varying in time and place, and the Arsenic concentrations in the pumped water is unpredictable and varying over time.

The survey conducted by BGS showed that of the tested ca. 3500 tube wells 42% exceeded the WHO's guideline value of 10 µg/l and 25% exceeded 50 µg/l (MCL of Bangladesh).

A solution can be to mark the shallow tube wells that are free from Arsenic and divert the people to these tube wells. Marking of the tube wells is already done in Bangladesh. There may be significant socio-economic barriers using this solution. One of the barriers could be that women are traditionally not expected to leave their Bari (a cluster of related households). The markings will be without effect if used in places where more than 75% of the tube wells are contaminated with Arsenic. It further requires monitoring of the tube wells occasionally to be certain that the tube well is free from Arsenic over time. There are studies showing that the Arsenic concentration in the tube wells changes over time, with high concentrations during summer compared to winter.

Tube wells may also have been unfavourably placed with risk of contamination from local sources e.g. too near to the household's latrine, or seepage through cracks in the slabs.

Shallow tube wells may be a safe way of supplying safe water both in terms of hygiene and Arsenic if combined with a proper and reliable treatment of the pumped water. The option may consist of a proven filtering method combining Arsenic and particulate removal.

### **Deep tube well water (utilising ground water at considerable depth):**

The ground water extracted from deeper aquifers is usually free from Arsenic. It is difficult to give an exact depth at where this deep aquifer exists. Usually water extraction below 150/200m deep is considered as deep aquifer, but in many cases this can be below 200m. The study by BGS showed that only 5% of the deep tube well waters had an Arsenic concentration above 10 µg/l and 1% exceeded 50 µg/l. This solution can look like a long-term solution, but if the deeper aquifer is not separated from the upper aquifer the Arsenic concentration can increase with time. High Arsenic concentration in the deep ground water does not imply that the ground water is contaminated, but could be due to leaching from shallow upper aquifers. Another possibility could be improper sealing of the boreholes. Experimentation by sealing the borehole at the level of an impermeable layer in the sediment is yet to be conducted to draw conclusions. Therefore monitoring of Arsenic concentration is also required for this solution.

The DPHE has divided the coastal regions into 3 types of areas: shallow tube well areas, deep tube well areas and mixed shallow and deep tube well areas. In the coastal areas with possibility of saltwater intrusion in the shallow tube wells, the water supply is mostly based on the small diameter manually constructed deep tube wells. Therefore installation of deep hand tube wells could be a better solution in these coastal areas. However, according to Ravenscroft P. (Proceeding of Deeper Aquifers of Bangladesh-A review meeting, 2000) an increase in the ground water withdrawal from deeper aquifers may lead to contamination of the deeper aquifers by vertical leakage of Arsenic and both lateral and vertical seepage of saline water. Based on the hydrogeochemical studies, field evidence, and numerical modelling they suggested that the Arsenic contamination in the deeper aquifers would occur only after many decades or even centuries. Although these results are encouraging for using the deeper ground water as a possible source of Arsenic free water, the risk of salinisation is probably real. In the coastal belt there is a saline water zone between the upper and main aquifer.

Apart from Arsenic, there are other elements like Manganese, Uranium and Boron contaminating the ground water. The DPHE/BGS national hydrochemical survey shows that 35% samples exceeded the WHO guideline value for Manganese (500 µg/l), 5% exceeded the WHO guideline value for Boron (500 µg/l) especially in the southern coastal region, 50% of the subset samples selected for trace analysis from national survey exceeded the WHO's provisional guideline value for Uranium (2 µg/l).

The following main points can be drawn from the review meeting held ("Deeper Aquifers of Bangladesh-A review Meeting, 2000") in August 2000 by the DPHE with support from UNICEF and the water & Sanitation program-South Asia with experts:

- The definition of the deep ground water zone is: below the Arsenic contaminated shallower ground water zone, preferably separated by aquicludes or aquitards<sup>1</sup>, or the deepest level Arsenic uncontaminated and safe ground water zone of one layer system, separated by an artificial seal. It is usually below 150 m.
- Regarding how long the deeper aquifer can remain safe: This depends on many factors most important the presence of an aquitard. Research is needed to answer this question. Water from the deeper aquifers should not be exploited for irrigation purposes. The aquitard is known to exist across most of the coastal regions of Bangladesh at a depth of more than 200 m. Further north the clay aquitard is of variable thickness and is shallower (e.g., 30-70 m thickness at a depth of 160 m at Meherpur and Magura). It thickens towards the coast. The aquifer does not exist at Faridpur and may be expected to be absent along the channels of deep incision that were cut across the Bengal fan during the last glacial maximum. Therefore it may be absent elsewhere in places.
- The use of deep aquifers is not feasible in areas:
  - Saline water is within or near the deeper aquifer
  - Gas prone areas such as Sylhet basin
  - Locations where an aquiclude between the shallow and deeper aquifer is missing.

Deep tube wells may be a way of getting water low in Arsenic. However, the complexity and costs are significantly higher than for most other well supplies and may not be a durable solution. The deep tube wells may become Arsenic infested over time as the sediments at depth also contain Arsenic compounds, which may be mobilised if the redox conditions change, or if leaking from upper aquifers occurs.

## **Treatment of Arsenic contaminated water:**

The available removal methods in the literature are primarily based on 4 principles: coagulation/co-precipitation, adsorption onto surfaces, membrane processes and ion exchange methods.

When developing a removal method at household and community level, where the analysis of Arsenic is not carried out periodically as in case of large treatment units and where there is a possibility of change in the Arsenic concentration from time to time and place to place, many problems can occur, some of which are listed below.

### ***Coagulation/co-precipitation:***

The processes involved in Arsenic removal by coagulation are addition of metal salts, sedimentation and filtration. The common coagulants added in the pH range of 4-8 are Iron and Aluminium salts and  $\text{Ca(OH)}_2$  is added at pH above 10. The removal efficiency for As(V) is usually much better than for As(III), therefore pre-oxidation of As(V) is necessary to increase the removal efficiency.

The amount of coagulant to be added depends on the initial Arsenic concentration, so if the initial Arsenic concentration is higher than the design Arsenic concentration, the added coagulant is not enough for the expected Arsenic removal down to 50 µg/l. This problem has been experienced in

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<sup>1</sup> Layers of clay, peat or loam, which are considered to be impermeable, are termed as aquicludes, or when almost impermeable, aquitards.

case of the DPHE-DANIDA bucket treatment unit, where the unit works well at lower initial concentrations, whereas at higher initial Arsenic concentration the removal efficiency is very poor.

**Presence of other ions:** If there are other ions present such as Phosphate or Silicate, which compete for the adsorption sites of the coagulant added, the amount of coagulant needed is higher than expected when only Arsenic is present.

**pH of the water:** The coagulation of the particles changes with change in the pH depending on the point of zero charge of the particles. This may lead to increase in the time necessary for settling and change in the adsorption capacity of the coagulant.

To apply the technologies based on Coagulation/Co-precipitation in the household removal to achieve the acceptable Arsenic concentration in the drinking water, the technologies should state clearly to what concentrations these technologies could be applied. Unless the water parameters are the same these technologies will not achieve the same removal level as expected. Another problem with these technologies may be the daily disposal of the sludge. The sludge produced from the Arsenic removal technologies contains Arsenic and improper disposal of this sludge on the land may cause leaching of Arsenic to the surface waters.

The experience on the various developed Arsenic removal units from the various Arsenic mitigation projects in Bangladesh on removal of Arsenic using the coagulation/co-precipitation principle is that the Units are not consistent and reliable in removal of Arsenic in different areas.

These technologies can be applied at the community level since the number of units to be installed at the community level will be fewer compared to household level and hence the water parameters can be tested and proper coagulant dosage can be administered.

#### ***Adsorption on activated/coated surfaces:***

Activated/coated surfaces are used to adsorb Arsenic from water and hence remove it from drinking water. The adsorbents like Activated Alumina, Granulated Ferric hydroxide, Hematite, Activated Carbon are studied for their adsorption of As(III) and As(V) and the studies show that adsorption of As(V) is better than adsorption of As(III).

These techniques look simple in operation since in most of the cases no addition of chemicals is required, so the consumer does not have to spend time in adding the chemical, remembering how much chemical to add. The units work as a continuous system where water is poured at one end and collected at the other end. Therefore these techniques look more lucrative than the coagulation principles. The problems with these techniques are that the adsorbent media has to be regenerated with frequent intervals and the time after which the media has to be regenerated depends on the same factors like concentration of Arsenic, pH of the water, presence of other ions as in case of Coagulation and co-precipitation method. Other problem is that the regeneration of the filter media requires special skills; therefore agreements have to be made with the supplier regarding the regeneration of the filter media or replacement of the filter media. The cost of these units is usually high compared to the Coagulation/Co-precipitation techniques. Another problem with these techniques is clogging of the filters with silt/clay and ferric oxides.

The experience in the Arsenic Mitigation Project with these techniques showed that they are good during the evaluation period with occasional problems of clogging of the filters and slow flow rate.

An attempt was made to categorise the treatment units according to their cost of purchase, operation and maintenance cost (Appendix 3).

### ***Ion exchange:***

The principle of Ion exchange is that Arsenic is adsorbed on to resins in exchange of other ions that are less strongly adsorbed compared to Arsenic. Arsenic removal with Different Ion exchange resins has been tested for their removal of Arsenic from water. Pre-oxidation of As(III) is necessary to achieve removal of Arsenic from water since As(III) is present in neutral form and As(V) is present as an anion at neutral pH.

### ***Membrane processes:***

The principle of membrane process is that water is allowed to pass through special filter media, which physically retain the impurities present in the water. Reverse Osmosis, Electrodialysis and Colloidal floatation are some of the membrane processes studied, and the results show that removal of As(V) is better than As(III).

### **Experiences with Various treatment options:**

For a detailed description of the chemical process involved in the various principles and the advantages and disadvantages of these four methods see Appendix 2.

These above 4 principles can be used to develop treatment technologies at both household level, tube well level, community level and village level depending on the ease of operation and maintenance, cost of the material and maintenance etc. Table 2 presents the various treatment technologies that have been developed based at the household levels, and at the tube well level. These developed treatment technologies will have the same advantages and disadvantages as the principles. Some of the developed treatment technologies use a combination of the principles and indigenous materials like brick chips, Iron filings, clay etc. These technologies are categorised as indigenous technology under the principles.

All the above mentioned principles require oxidation of As(III) to As(V) to increase the efficiency of Arsenic removal. The oxidation of As(III) to As(V) can be achieved by UV-radiation, and oxidants like free chlorine, hypochlorite, ozone, permanganate, solid manganese dioxide and hydrogen peroxide/ $\text{Fe}^{2+}$  (Borho & Widerer, 1996). Iron in presence of sunlight and citric acid can oxidise As(III) to As(V) (SORAS method).



Level	Principle	Name of the filter	Chemicals used
Individual households	Coagulation/Coprecipitation	DPHE-DANIDA Bucket Treatment Unit	Alum
		Improved DPHE-DANIDA Bucket Treatment Unit	Iron
		Steven's Institute Technology (Iron)	Iron
		Garnet Filter BCSIR Filter unit	Iron
		Passive sedimentation	Naturally occurring Iron
		SORAS	Naturally occurring Iron in transparent bottles and lime
	Adsorption onto Activated/Coated surfaces	Alcan Enhanced Activated Alumina filter (MAGC)	Activated Alumina
		BUET Activated Alumina Filter	Activated Alumina
		BUET Iron coated Sand	Iron coated sand
		ARU of Project Earth Industries inc., USA	Activated Alumina and Composite metal oxide
	Ion Exchange:	Tetrahedron	Resin
	Membrane Process	MRT-1000	Membrane
		Reid System	Membrane
		Techno-food	Membrane
		Reverse osmosis and bicycle pump.	Membrane
	Indigenous:	Sono 3-kolshi Filter:	Iron filings
		Shapla filter:	Iron coated dust
		Chari filter	Brick chips and Inert Aggregates
		Shafi Filter	
		Adarsh Filter	
Treatment Units attached to tube wells:	Coagulation/coprecipitation:	Iron Removal Plant:	Naturally occurring Iron
		AIHH&H	Alum
		Fill & Draw Unit	Alum
	Adsorption onto Activated/Coated surfaces	Oxide India Technologies	Activated Alumina
		Adhiacon:	Filter media
		Alcan Enhanced Activated Alumina filter	Activated Alumina
		AdsorpAs:	Granular Ferric Hydroxide
		PHED	Hematite
	Ion Exchange:	Ionochem Water Systems International	Resin
		Insitu Arsenic immobilization	Ingestion of aerated water into the tube well

Table 2: Different Removal methods available at household and community level

Most of the indigenous methods can be classified as continuous methods in contrast to coagulation/coprecipitation, which is a batch process. For example in Sono 3 kolshi method the Iron

filings present comes in contact with oxygenated water and Iron gets oxidised to Fe(III) and hence the process acts as coagulation and coprecipitation. The release of Iron to water from Iron filings will continue so long there are Iron filings. Therefore the advantages and disadvantages of these methods can be compared with the adsorption onto activated/coated surfaces and ion exchange method, except that the material is locally made and can be bought locally without the need for regeneration as in case of Adsorption onto activated surfaces.

#### *Other prerequisites:*

Selection of a suitable method to supply Arsenic free drinking water depends on many factors. In developing countries like Bangladesh, where centralised water supply is not available in rural areas the following factors have to be taken into consideration:

- Simple
- Low-cost
- Able to function without electricity
- Versatile, able to work on various water sources and in a wide variety of settings: villages, cities, etc.,
- Include provisions for a safe method of disposal of Arsenic rich-sludge
- Based on local resources and skills
- Accessible to community and women's group

Apart from the above the decision about whether Arsenic mitigation should be based on the community level or household level will vary from place to place depending on the people who are supposed to use the system.

Some of the experiences from the various Arsenic mitigation projects at community level are:

- Even though in the beginning of the project the formation of a community is good, but after the procurement of the Arsenic removal unit the community dissolves and there is no one to take the responsibility to maintain the unit.
- Some times the landowner where the unit is installed denies other to use the unit
- And so on.

## **QUALITY CONTROL AND ANALYSIS OF ARSENIC**

Available literature (Ahmed F.M. 2002) shows that the Arsenic concentration in the shallow tube well water can increase with time, that is even though a tube well is categorized as free from Arsenic it may contain Arsenic when tested after a certain time. The literature also shows that there is seasonal variation in the Arsenic concentration of the tube wells, resulting in nearly twice as high concentrations at the end of the wet season (Oct-Dec) compared to the end of dry season (April-June). This indicates that a tube well may be used for drinking during summer but cannot be used during rainy season and winter. The literature also indicates that the water from deep tube wells free from Arsenic when installed may contain Arsenic after a certain time if the upper Arsenic contaminated aquifer is not separated from the deeper aquifer.

These observations indicate that to ensure Arsenic free water it is not enough to screen all the Tube wells once, but there is a need of monitoring the Arsenic free tube wells at a certain time intervals to make sure that the tube well is continued free from Arsenic.

The frequency of monitoring is not easy to comment on. It may be advisable initially to follow some selected tube wells biannually for say 6 years to see how the situation develops, and learn about the dynamics.

## ***FIELD TEST KITS***

A list on the various field test kits available in the Market is shown in Appendix 5. Most of the field test kits are based on the principle of Bromide stain method and the relative standard deviation of this method for a solution of 50 µg/l in distilled water in a round robin exercise was 75% (Rahman et al. 2002). The presence of sulphide (1 – 10 mg/l) interferes in the development of the colour, but sulphide is not common in groundwaters. In case of field kits based on NaBH<sub>4</sub> the interference due to sulphide can be expected, because reduction of sulphate due to borohydride produces sulphide. This interference can be removed if the method is used in the laboratory, but in the field it is not possible to remove the interference.

Most of the Analysis work carried out in Bangladesh under the screening programme by various agencies is using different field test kits and these Test kits were controlled for their accuracy of analysis using various laboratories in Bangladesh. Based on the published literature the literature review (Rahman et al., 2002) showed that at least 1.3 million water samples from hand tube wells were analysed by field kits and an estimated 1 million tube wells were colored red (> 50 µg/l) or green (< 50 µg/l) based on the Merck kit, which has 100 µg/l of Arsenic as the minimum detection limit. Using the same test kit, the BAMWSP analysed 617 366 hand tube wells and DPHE-UNICEF analysed 403 651 tube wells. The DCH analysed 137 971 samples by Merck kit and 19436 samples by NIPSOM. Other organisations from Bangladesh such as the NGO Forum, Grameen Bank, CARE, BRAC also used the Merck kit and NIPSOM kit for testing. The Merck doubling kit (Detection limit 10 µg/l) and Hach kit (detection limit 10 µg/l) were considered for use in the ongoing projects by many organizations. A statistical analysis of the results of 240 Hand Tube wells by the new Merck doubling kit and AAN kits and checked by using AAS with continuous Hydride Generation as reported by BRAC, Bangladesh showed that

- In the range 1-50 µg/l: Around 70% of the results by AAN and Merck doubling kit were true, where as 25.6% showed higher concentration than 50 µg/l.
- In the range 50.1-100 µg/l: only 37% of the results by AAN and Merck doubling kit were true, where as around 47% of the Merck kit results showed a value less than 50 µg/l.
- In the range > 100 µg/l: only 51.8% by the Merck doubling kit were true, and the remaining showed Arsenic concentrations less than 50 µg/l.

The above results even on the better test kits indicate a substantial possibility of either over estimation or under estimation of the Arsenic contamination in the surveyed villages.

AMPP of DPHE-DANIDA also used the original Merck kit and at that time the kit had only the minimum detection level of 100 µg/l, therefore this kit could not measure down to the Bangladesh

standard of 50 µg/l. The comparison of field test kit results compared with laboratory results by the AMPP of DPHE-DANIDA also showed that

- Out of 29 results showing zero Arsenic concentration by Merck Field Test kit, 15 (52%) were having an Arsenic concentration above 50 µg/l in the laboratory test.
- The Merck kit generally showed lower concentrations in the lower concentration range (below 0.26 mg/l) and higher concentration in the higher concentration range (above 0.26 mg/l) compared to the laboratory results.

A joint evaluation of the field kits by NGO forum and SOES (NGO forum, 1999) concluded that the “mercury bromide stain method is incapable of providing a quantitative meaningful result below concentration of 150 µg/l (Water supply and Sanitation Program).

The experience of UNICEF using the Merck kit (manufactured in Germany) are that the results from the field show that Merck kit is relatively reliable in showing whether the Arsenic concentration in the water is below 20 µg/l or above 100 µg/l. To be on the safe side the UNICEF marked the tube wells containing Arsenic between 20-50 µg/l as unsafe. According to the Mediabrief on Arsenic Mitigation in Bangladesh by UNICEF Bangladesh there is no reliable field kit that can accurately detect Arsenic at 50 µg/l is available commercially in the market. According to the UNICEF-DPHE 45 upazila Arsenic mitigation project used second-generation Merck kit that was accurate to 50 µg/l, but was difficult to read at 10 µg/l.

USEPA has conducted rigorous reviews on the following field test kits in July 2002.

- Peters engineering As 75 (PeCo 75) Arsenic Test Kit (As75)
- AS-TOP Water Arsenic Test Kit
- TraceDetect Nano-Band<sup>TM</sup> Explorer Arsenic Test Kit
- Industrial Test Systems, Inc. Quick<sup>TM</sup> Arsenic Test Kit

The performance of Nano-Band, and AS-TOP Water, was not good. The performance of the other two test kits was better but not satisfactory. BAMWSP used the PeCo 75 test kits in the project on the Rapid Assessment of Household level Arsenic Removal Technologies Phase I and found that the results obtained with PeCo 75 were not satisfactory compared to the laboratory results. The instrument was under-reading significantly until it was decided to modify the procedure. The samples with Arsenic concentrations below 100 µg/l does not require any dilution while samples in the range 100-500 µg/l required a 5 times dilution and samples greater than 500 µg/l required 10 times dilution. A new developed version of this Kit is on the way. If this is the same version available in the market, then measurement of Arsenic in the field using this field kit could be difficult, because if the samples above 100 µg/l require dilution, distilled water has to be carried along. UNICEF-DPHE 45 upazila Arsenic Mitigation Project are planning to use 3-stage HACH in 4<sup>th</sup> phase, which according to them can measure Arsenic down to 10 µg/l but are expensive.

One of the reasons for the slow progress of the BAMWSP given was that there is lack of test kits of an appropriate design. According to the Rapport on “An overview of the Arsenic Issues in Bangladesh”, the HACH kit has been modified and the new developed HACH EZ is producing encouraging results and is now recommended by BAMWSP, UNICEF, WaterAid Bangladesh and many other organisations for field testing.

## ***LABORATORY ANALYSIS***

Arsenic can be measured in the Laboratory using various methods, but the principle involved in most of the methods is to produce Arsine gas using  $\text{NaBH}_4$  and then either measure it using advanced techniques like Atomic Absorption spectrometer (AAS) or using colourimetric techniques like the Silver Diethyl Dithiocarbamate method (SDDC). Other complicated and/or expensive techniques of Arsenic measurements are Neutron Activation Analysis, Inductively coupled Argon Plasma Emission Spectrometry, Anodic stripping Voltametry etc. The selection of method for analysis depends on the minimum detection level and the expenses involved.

The guideline value for Maximum contamination of Arsenic set by the Government of Bangladesh is  $50 \mu\text{g/l}$ , where as the provisional guideline value set by the WHO is  $10 \mu\text{g/l}$ . As it was mentioned before that there is a need for revising the guideline value, it is possible that in the near future the guideline value in Bangladesh is also lowered.

It is possible to measure the Arsenic concentrations down to  $10 \mu\text{g/l}$  using the colorimetric method, but according to the available literature the uncertainty is very high at concentrations below  $25 \mu\text{g/l}$ . Therefore the use of these methods in future for measurement of Arsenic is not recommended if the guideline value is reduced to below  $25 \mu\text{g/l}$ . The time required for each analysis is long, approximately 30 minutes. The advantage of this method is that the facilities required for establishment of a lab is very few, therefore it is easy to establish a laboratory.

Depending on the method used in the advanced techniques using AAS, a minimum detection limit of  $0.5 \mu\text{g/l}$  or lower can be achieved. The number of samples that can be analysed per hour can vary between 60-10, depending on the arsine generation, i.e., whether it is batch system or continuous system. The disadvantage compared to the colorimetric method is that the capital cost and maintenance cost is very high. But if the required minimum detection level is  $10 \mu\text{g/l}$ , then the colorimetric methods cannot be used.

It is not only the Field Test Kits that are inaccurate, but also the Laboratories in Bangladesh are not accurate. A study (Aggarwal et al., 2001) on inter laboratory comparison of Arsenic analysis in Bangladesh showed that of the 17 participating laboratories less than one third of the 17 participating laboratories obtained results that were within about 20% of the value obtained by a specialised laboratory with state-of-the-art facilities. Some of the Laboratories using the advanced techniques like Atomic Absorption Spectrometry with Graphite furnace and Atomic Absorption Spectrometry with Hydride generation failed to show the correct value for the reference sample. There was one laboratory using the SDDC method produced high results at lower concentration of reference value. Among the participating Laboratories the DPHE-DANIDA laboratory in Noakhali also took part.

## ***LABORATORY ANALYSIS VS FIELD KITS ANALYSIS***

The above observations indicate that the Field Test Kits used in screening of the Tube wells shows grossly inaccurate results. It is also obvious that reliable results could not be obtained for the same samples in different laboratories of Bangladesh. To combat the Arsenic problems in Bangladesh it is very important to be able to measure the Arsenic concentration accurately.

Measurement of Arsenic is rather complicated. The experience with the development of Arsenic measurement method at the Laboratory of Technical University of Denmark showed that the measurement depends on many factors, and care must be taken during the measurements. The same was the case when the SDDC method was used during 1997-98 at DTU. These experiences showed that even under the same conditions the amount of Arsine generated was different from day to day and unless the standards are measured on the same day using the same chemicals the obtained results can vary by more than 50%. In case of field test kits the standards are made in the form of colours developed on paper strips using one standard and these colours are compared with the colours developed by the samples. Therefore there can be lot of variations in the value obtained by the field kit and the actual value. The literature review shows the field workers, who are responsible for measuring Arsenic with field kits got only 2-3 days training for using the field kit. In addition the chemicals used for the analysis of Arsenic are poisonous and care must be taken during the handling of the chemicals.

From the above observations on the difficulty in Arsenic analysis and the necessity to analyse the Arsenic concentration at lower concentration levels, it is not advisable to analyse Arsenic concentrations using a field kit, which has a minimum detection limit of 100 µg/l, despite that the screening can be achieved in less time. The field test kits are inaccurate leading to false identification of the tube wells in terms of Arsenic contaminated. There are also other problems using the field test kit. In the laboratory with good exhaust there is very little effect on the people working with the Arsenic analysis whereas in the field the effect on the workers may be very high.

It is possible to set up a system to transport the samples to the laboratory for analysis of the samples provided that a quality control system is set up, the long term solution to the monitoring task may be a number of specialized laboratories. According to Appendix 4, the cost of analysing 7.5 million tubewells for Arsenic in two years using field kits and laboratory analysis will be the same and around 70 AAS are required to analyse the samples within 2 years. There exists at least 4 laboratories using AAHG (Aggarwal et. al., 2001), but there may be more. The possibility of using the capacity of these Laboratories and establishing other laboratories should be examined. It is absolutely necessary to quality control the laboratories by inter-laboratory calibration. The Arsenic problem also exists in the neighbouring country India and other nearby countries like China, Taiwan and Thailand. Therefore it is also advisable to perform inter-laboratory calibrations in the region to assure the quality of the analysis.

## **DANIDA AND BANGLADESH ACTIVITIES:**

The Rural water supply program in Bangladesh under DANIDA covers 8 coastal districts of Barisal, Pirojpur, Jhalakathi, Patuakhali, Barguna, Noakhali, Feni and Laksmipur covering 28 upazilas and municipalities. The various initiatives taken by DANIDA and Bangladesh to mitigate the Arsenic problem in Bangladesh are described in Appendix 6.

Since DANIDA funded Arsenic mitigation component installs Deep Hand Tubewells to mitigate the Arsenic problem, this section will contain the information about the protocol on installation of deep hand tubewells.

A final draft for the general guidelines/rules for Installation of deep hand tube wells in Arsenic affected areas has been established by the BAMWSP. The main features of the guidelines are as follows.

- Installation of a deep tube well is considered in Arsenic affected areas only when alternative options like dug well, pond sand filter, and rainwater harvesting are unsuccessful. Arsenic free deep irrigation tube wells may be used as source of drinking water to the community through pipe system. BAMWSP will start one deep tube well for each 100% Arsenic contaminated village and gradually switch over to other Arsenic contaminated hotspots (>40% contaminated areas).
- A committee will be formed to review the situation and decide regarding installation of deep tube wells.
- BAMWSP will collect all the particulars of test tube wells in Arsenic affected areas and information on well logs. Based on the available information Arsenic free tube wells will be plotted on the map, and a decision on suitable depth for installation of Deep hand tube wells at selected sites will be taken. Observing all these precautions a deep tube well with improved well design including a clay seal will be installed.
- Installation of a deep tube well in an Arsenic affected area will undergo exploration procedure including geophysical logging.
- If the water is found acceptable with regard to Arsenic concentrations and other critical parameters especially chloride, the tube well will be retained and will be allowed to be used by the community only for cooking and drinking purpose. If the water quality requirements are not met the tube well can be retained to be used for household purposes other than drinking and cooking or may be sealed.
- Monitoring will be done on successful deep hand tube well at specific time interval during the operation of the tube well for changes in the Arsenic concentration or any other critical parameters.
- For community mitigation activities through community action plan, one deep tube well will be provided for minimum 500 users.
- Tube wells that would trap water from below the Pleistocene red clay would be defined as deep tube well.
- The protocol should be followed by all agencies involved in sinking deep hand tube wells in Arsenic affected areas.

The Bangladesh authorities have described the actions to be taken to combat the situation in shortest possible time and is described in a draft form “Action plan to ensure safe water supply in Arsenic affected areas in shortest possible time” and the main point in the draft are as follows:

- Villages more than 80% contaminated should come under this Emergency water supply programme. For areas where contamination is 80-40 % a longer term and demand-responsive approach could be designed. DPHE’s normal program should also continue in these areas. In upazilas, where screening has already been completed, the emergency water supply program should be commenced immediately. In other areas this program should start immediately after the screening is complete.
- A service level of one safe water source (only for drinking and cooking water) for 50 families.

Source of supplying Arsenic free water:

- Dug wells can be identified as the appropriate technology in areas where no deep aquifer is available and perennial surface water sources are scarce.
- In areas where the presence of an impervious clay layer between the shallow and deep aquifers is proven, deep hand tube well can be identified as the appropriate technology for those areas. Excepting a few, these areas are mostly in coastal regions.
- For areas, where construction of dug wells is not possible and there is no deeper aquifer, treatment of surface water through pond sand filters may be identified as the appropriate safe water supply technology. These areas are mostly in the southwestern coastal regions.
- It is recommended that the government's role in rainwater harvesting should be limited to promotional activities.
- It is not advisable to consider Arsenic removal technologies as appropriate options until there has been formal verification of the technologies.
- Rural piped water supply could be a prospective option to be promoted.

An analysis was made by the DPHE-DANIDA Arsenic mitigation component to evaluate the differences between the DPHE-DANIDA strategy to mitigate the Arsenic problem and the protocol for Installation of Deep Hand Tubewells, which are as follows:

- The DPHE-DANIDA Arsenic component does not investigate the alternate water supply systems before installation of a deep hand tube well. The available alternative options are tried on pilot basis by the R&D component.
- The DPHE-DANIDA component installs 1 deep tube well per 250 users against the 500 users according to the DHTW protocol.
- The DPHE-DANIDA component installs 3-4 deep tube wells per each village against the recommendation of the protocol of 1 deep tube well for each village containing in the hotspots with Arsenic contaminated tube wells above 40%.
- The DPHE-DANIDA component installs the deep hand tube wells without based on any map on safe Arsenic aquifers.

The team from the DPHE-DANIDA component responsible for analysing the implication of the protocol guidelines on DPHE-DANIDA component expressed the main concern for not following the protocols in future was that it may delay the process of DHTW.



## **DISCUSSION ON PROPER CHOICES FOR LONG TERM MITIGATION OF ARSENIC CONTAMINATION IN BANGLADESH:**

When discussing a proper choice for a long-term mitigation of Arsenic contamination in Bangladesh the first question that arises:

- What are the possible roots of contamination?
- What should be the allowable maximum concentration?

### ***SELECTION OF GUIDELINES***

The USEPA has conducted an extensive research on the appropriate guideline value for US and came to the conclusion that the most cost-effective and practically achievable guideline value would be 10 µg/l and this value has been adopted, even though this value gives higher risk than the usually accepted 10<sup>-6</sup> level. As mentioned in the risk assessment part that at the same level of exposure to Arsenic concentration compared to the people in the western world the people in Bangladesh are at more risk.

The Bangladesh people are not only exposed to Arsenic through drinking water but also through food and this study shows that in case of Bangladesh at an exposure of 50 µg/l in drinking water the exposure through food also plays a major role in the exposure. The population exposure to inorganic Arsenic through food is very less in US than in Bangladesh.

The water consumption in the food preparation is also very high compared to the western world, since the main food is rice, which may lead to a daily water consumption of 5 l against WHO assumption of 2 l. The available literature shows that people in rural areas prefer to use the pond water for cooking and bathing purpose and the tube well water for drinking purpose. If this is true, then the consumption of Arsenic contaminated tube well water would be around 3.5 l instead of 5 l. These things indicate that the allowable maximum Arsenic concentration should be lower than the present value of 50 µg/l in order to provide secure drinking water. The presentation of the UNICEF-DPHE 45 upazila Arsenic Mitigation Project also questions the appropriate guideline that is whether it should be 10 or 50 µg/l. The choice depends on many factors like:

- How much risk the country can accept
- The Public pressure for security
- Whether it is economically and practically feasible
- Whether the same amount of money can be used in betterment of other factors to reduce the risk

### ***ARSENIC EPIDEMIOLOGY***

Until now there are no epidemiological studies available from Bangladesh, which shows the relationship between amount of Arsenic ingested and the related risk. The symptoms due to Arsenic

poisoning takes 10-15 years to develop and in case of the data from Taiwan people under age 20 did not show any Arsenic symptoms. In case of Bangladesh also children show symptoms of Arsenicosis. The actual reported cases in Bangladesh are very less compared to what could be expected based on the results from Taiwan. This could be due to the limited time of exposure to Arsenic. According to Figure 1 the number of tube wells installed increased drastically since the 1990's, which indicates that a large number of people have only have been exposed to elevated Arsenic concentrations for 5-10 year. This could explain why the numbers of Arsenic patients are less compared to what could be expected.

Another reason could be that even though people consumed the Arsenic contaminated water since 1960's the consumption of water containing was low compared to 90's. This could be because there were few tube wells, therefore people had to fetch the water from a distance and hence will use the tube well water only for drinking and use pond water for cooking. And storage of water containing high Iron concentrations along with Arsenic reduces the Arsenic concentration in water through precipitation with Ferric oxides.

A third reason could be the uncertainty in the lower concentration range, since there are no reliable data available in the lower concentration range. There is also uncertainty on the effects of Arsenic at the lower concentration range below 100 µg/l, like whether there is any methylation capacity in human beings that will reduce the toxicity of Arsenic. The present models assume that there is no threshold for the effect of Arsenic on human beings. This may overestimate the risk in the lower concentration range. Another drawback of the present epidemiological studies on Arsenic toxicity is that these studies did not include the consumption of the Arsenic through food. A study from Taiwan indicates that consumption of Arsenic through food was also very high from the studied area and this will also overestimate the risk through drinking water. Until so far there is very limited data from Bangladesh showing the effects of Arsenic (Milton & Rahman 1999, Rahman and Axelson, Axelson, Rahman and Tondel 2000, Milton et al. 2001) and no data available from Bangladesh showing the dose response relationship of Arsenic. Work by Milton & Rahman 2002 shows that there is an evidence of respiratory effects due to ingestion of Arsenic. The UNICEF-DPHE Arsenic mitigation project identified Arsenic patients with a prevalence rate of 0.98/1000. In the literature there are some indications that such work is being carried out, but the results are not available yet.

## ***EXPOSURE THROUGH FOOD***

As mentioned earlier the Arsenic exposure through food is also most probably high (since the eating and drinking habits of people in West Bengal are similar to the people in Bangladesh). Some studies show that the Arsenic concentration in the food increases if the irrigation water used contains Arsenic. Another possibility for the high Arsenic concentration in the food grains could be high Arsenic concentration in the fertilizers used. There was also a suggestion that the possible contamination of Arsenic in the ground water was the extensive use of fertilizers. This theory was ruled out later by many scientists, but this could still be a cause for the high Arsenic concentrations in the food products.

The Arsenic mitigation that is going on in Bangladesh until so far has not taken the possible route of Arsenic exposure through food into consideration. Research work should be carried out to see the

relative contamination of food through irrigation water and fertilizers. Suitable measures could then be taken to reduce the overall exposure of the people to Arsenic.

## ***MONITORING OF ARSENIC CONTAMINATION***

The next step after the establishment of a suitable guideline value is how to measure the Arsenic in ground water. The number of tube wells that has to be tested is enormous and an immediate action has to be taken to combat the situation. As discussed in the quality control section that even though the screening of the tube wells can be completed in comparatively less time the used field test kits are not suitable to measure the concentration in the range of 50 µg/l or below. It is surprising to see that even though the laboratory test showed that the field test is not appropriate to measure the Arsenic concentration in the desired range the major screening work in Bangladesh has been carried out using these test kits. The AMPP used the Merck Kits with minimum detection limit of 100 µg/l, for characterising tube wells as safe or unsafe, which is an impossible task. The test results by AMPP also showed that the Merck kit is not reliable. The DANIDA's screening programme to test about 130,000 TWs also uses Merck test kit (not sure whether it is the new improved Merck with minimum detection of 10 µg/l) for measuring Arsenic. The screening programme completed around 72,625 tube wells and found 60% as contaminated and 40% as uncontaminated. According the available results on test kits the actual picture on contamination can be very different than the real (Semi-Annual Progress Report 2002).

The use of field test kit could be justified since the screening work has to be carried out within short time and the only way presently of doing this is by field kits. But it is possible that the uncertainty regarding the safety of the tube well water with respect to Arsenic concentration, can be both overestimated and underestimated. As the Arsenic concentration in the tube wells changes over time, this monitoring could be necessary, the first year in selected tube at the end of the dry season and at the end of the wet season to see the seasonal variation and then 2-5 years to monitor the changes over time. The other possibility could be to collect and analyse the samples at the end of the wet period, where it is expected the Arsenic concentrations is highest. The only sustainable method for analysis of Arsenic could be analysing them in laboratories using the advanced techniques like Atomic Absorption Hydride Generation that have lower detection limit and can cope with high number of samples. The possibility of using the existing laboratory facilities in Bangladesh should be explored. The established laboratories should also be quality checked by inter calibration and intra calibration with frequent intervals.

## ***THE LONG TERM SOLUTION TO REACH CLEAN WATER***

The next step after characterising the tube wells is to find the long-term solutions for supply of Arsenic free drinking water. The choice of the proper solutions depends on many factors. The concentration of Arsenic has to be monitored in all the available cases except when rainwater harvesting or surface water is used as supply options.

The first step in view of the Arsenic mitigation in the affected villages is to screen all the tube wells (both shallow and deep tube wells) and point out the safe tube wells with respect to Arsenic concentration. From the available literature it can be seen that most screening of the tube wells is done using field kits, which are not reliable in the allowable concentration range, with the

consequence of that the estimated % of tube wells that are contaminated with Arsenic is partly erroneous.

The main disadvantage of using surface water and rain water in comparison with Arsenic free ground water is that the surface water and rain water has to be treated properly before use for drinking purpose. The other problem is the people's acceptance of surface water for drinking purpose. The experiences from various Arsenic mitigation programs show that the acceptance of surface water for cooking purpose is large, but for drinking purpose is very small. The drawbacks of pond sand filtration are availability of ponds where there is no fish cultivation, algal blooms, or clogging of the filter beds. PSF were in use in Bangladesh, but there is no experience with rainwater harvesting. The experience gained so far shows that there are some difficulties like the thatched roofs are not suitable for collection of the rainwater and bacterial contamination of the stored water. Dug wells can be used as one of the long-term solution, since the Arsenic concentration in the dug wells is low and it is cheaper to install dug wells. People in Bangladesh used dug-wells in olden days. The drawbacks of dug well are bacteriological contamination, bad smell, sand boiling, and turbidity of water. Some studies show that not all the dug wells are free from Arsenic and if a new guideline value with lower Arsenic concentration is selected then may be some of the dug wells cannot be used. There is a need for research in developing this technology. Due to the bacterial contamination and some other problems as mentioned by the BAMWSP this technique is also not used widely. The available technology at present cannot be used as a long-term option for Arsenic mitigation.

The Experience of BAMWSP on alternate water supply sources using Dug well, Pond Sand Filter, and Rain water harvesting are as follows:

- Dug Wells: In loose soil conditions in areas like Chandpur district are facing the problems like sand boiling, well-collapsing and increased turbidity of water.
- Pond Sand Filter: Villagers do not maintain the ponds properly, which results in algal blooms in the ponds and wastewater finds access to the pond. Consequently the filter bed gets clogged frequently. The preparation of community to utilize PSF can take years.
- Rain water Harvesting: Should be installed in every household so that people feel that this is the only alternative option.

The protocol for deep Hand Tube wells suggests to investigate supply of Arsenic drinking water based on the dug wells, Pond Sand Filters and Rain water harvesting, but the experience from various agencies including BAMWSP show that these solutions are not accepted by the community due to many reasons. It is a good idea to investigate whether these solutions are already in use in these areas and the solutions are successful then the supply of Arsenic free drinking water can be based on these solutions. If not then successful implementation of these methods may take time and people will continue using the Arsenic contaminated water.

The other alternative source of infiltration gallery/well mentioned in section 3 requires a pond or river nearby and the experiences gained so far shows that the infiltration galleries are readily contaminated. Therefore even though the BAMWSP suggests using the PSF and rainwater harvesting as alternate sources of drinking water these solutions may not be appropriate. The shallow shrouded tube wells and very shallow shrouded tube wells have been tested in the coastal areas, but over-pumping may yield contaminated water.

The last option of the alternative supply of drinking water is deep tube wells. This option looks lucrative, since once the tube wells are installed then it is almost maintenance free and there is no possibility of primary bacterial contamination. The cost of this option is very high and to consider it as a long-term choice it is to be certain that the Arsenic concentration in the ground water should be free from Arsenic and salinity (especially in the coastal areas) in the long run. This may be assumed in presence of an aquitard, but until now there is no detailed data available about the presence of this aquitard. Therefore installation of a deep tube well without knowing about the presence of the aquitard is taking a risk. Even though the water at the time of installation of the tube well is free from Arsenic with time the Arsenic from shallow aquifer may percolate to the deeper aquifer and contaminate the water.

An attempt was made here to go through the available literature on Arsenic contamination in the areas where DANIDA has undertaken the water supply project and to evaluate whether there is any indication of presence of Arsenic in the deeper aquifer and how severe the areas have been affected. Appendix 7 shows the Arsenic concentration in some of the tube wells measured by BGS in 1999 in the areas where DANIDA is responsible for the water supply (Sector Programme Support Component Description, Arsenic Mitigation component, July 2000). The Appendix also shows the % of contaminated tube wells as measured by BGS, DPHE and assumed by appraisal team in the report on the sector program support component description. It can be seen from the Appendix that the % of Arsenic contaminated Tube wells assumed by the appraisal team in some of the thanas is higher than the BGS and DPHE value. It can also be seen from the Appendix that the number of tube wells tested in the Arsenic affected area by BGS are very few compared to the number of tube wells actually present in the different thanas. According to the rapport on the Sector program support component description, the number of tube wells in each thana were in the range of:

Shallow Tube wells: Public: 1100-7000 and Private 1100-11000 per Thana , Total: 130,000  
Deep Hand Tube wells: Public 175-2500 and Private 10-300 per Thana, Total: 44,450

These figures show that there already exist a large number of deep tube wells in this area and a survey of these tube wells can give an idea of the contamination risk of the deeper aquifers with Arsenic. The number of tube wells present in this area shows that the ratio between the number of shallow tube wells present and deep tube wells present in this area is 6.7:1 (The DHTW in Patuakhali and Barguna are not accounted since there are no shallow tube wells in this area). As the numerous studies suggests the coverage of shallow tube wells in Bangladesh is almost 2-3 households per each tube wells, then the 6.7:1 ratio indicates that around 20 households would be covered per one deep hand tube well.

The available information from the BGS shows that in one of the 11 thanas named Barisal sadar 2 deep tube well out of 7 were contaminated with 43 and 58  $\mu\text{g/l}$ . The special study area in the BGS studies shows that the Arsenic concentrations in ground waters from the deep aquifer in Lakshmipur have mostly low Arsenic concentrations (BGS final report summary). Monitoring of deep aquifers (150 m deep in Lakshmipur) for one year showed no increase in the Arsenic concentration in that period.

If a lower guideline value of 10  $\mu\text{g/l}$  is chosen then the number of thanas where the possibility of Arsenic contamination in the deeper aquifer increase to 3 thanas and there are four more thanas where the Arsenic concentration of one or more of the deep hand tube wells is close to 10  $\mu\text{g/l}$ . The discussion held at the workshop on deep aquifer showed that even though some deep tube wells

show that they are contaminated with Arsenic, it does not indicate that the aquifer is contaminated, but it could be due to the improper sealing of the borehole. It can also be that the information about the depth of the tube well is wrong. But the workshop also pointed out the possibility of salt-water intrusion in the deeper aquifer and contamination with Arsenic in the absence of aquitard. These results indicate that even though the alternative option of supplying drinking water through deep tube wells looks attractive this option may not be used without a prior screening of some of the deep tube wells in the areas to assess the possibility of Arsenic contamination in the deeper aquifer. As the above calculation shows it may not be necessary to install the DHTWs in the DANIDA area, since there already exists many DHTWs in these areas.

Another possibility is supply water as piped water in the areas where it is possible and could be explored. This is because even though deep tube wells are installed in the area the distance to the nearest deep tube well can be long and this may lead to that people start using the Arsenic contaminated shallow tube well water or surface water. Another advantage of piped water supply would be that there will be a formation of a community, or there will be someone who is responsible for the water supply. This may ensure that if there is a detection of Arsenic in the pumped water one of the treatment technologies can be effectively applied to reduce the Arsenic concentration to the desired level.

Regarding promotion of treatment technologies it may be feasible to promote the community based treatment technology in the places where possible instead of Household treatment units, this will result in fewer number of water outlets that have to be monitored. One of the possible solutions for the responsibility sharing could be to appoint a person who is responsible for the maintenance and monitoring of a number of tube wells.

The experience of various agencies working with Arsenic mitigation shows however that the water supply based on the community involvement is not successful, due to lack of community formation. Therefore in such cases the household treatment options would be better. Regarding promotion of the household treatment technologies, a thorough monitoring and development of the technologies are necessary for the village situation with different water parameters, before they can be promoted as long- term solutions.

## **IDENTIFIED NEEDS FOR FURTHER RESEARCH AND DEVELOPMENT**

Reviewing the available information and literature, the following topics have been identified in need of further research and development.

- There is a need and a unique possibility for research on the health effects of Arsenic and the exposure to Arsenic in case of the Bangladesh population in order to establish proper guideline values to protect the people against the adverse health effects of Arsenic.
- There is a need for research on the entry of Arsenic into the food system and the associated risks. The limited available literature shows that the Arsenic accumulation in rice depends on the rice variety, and not with the quality of irrigation water. The research should also focus whether the high Arsenic concentrations found in the foods may be due to the use of phosphatic fertilisers.

- There is a need for better understanding of the mechanisms for Arsenic mobilisation into ground water to help in assessing whether the deeper aquifers in the long term may become contaminated with Arsenic.
- There is also a need for aquifer mapping in the Arsenic contaminated area to identify Arsenic free ground water and to ensure that the water will remain free from Arsenic in the long run.
- There is a need for developing or selecting sensitive and precise field test kit, which may be locally produced. The available field test kits in Bangladesh are not adequate to measure the Arsenic concentration at the required level.
- There is a need to assist existing laboratories in developing fast and accurate procedures for Arsenic determination. This may be the best long-term solution.
- Research is needed to improve the available technologies for removal of Arsenic from water. Especially to focus on methods which at the same time sanitises the water.
- Research is needed to improve the alternative solutions like dug wells, pond sand filters and rainwater harvesting, which may always provide Arsenic free water, but nearly always at a hygienic risk.
- Research is needed to improve the drilling technology and proper sealing of the boreholes to prevent contamination of deeper ground waters with Arsenic.

## CAPACITY BUILDING

There are many organisations working on Arsenic mitigation in Bangladesh. A list on most of these organisation is given in the report by NAISU on "An overview of the Arsenic issues in Bangladesh". Many of these organisations are working on the same issues and have the same experiences regarding analysis of Arsenic using field kits, and implementation of various alternative water supply solutions. It will be a good idea if all these experiences are gathered when further implementation of any Arsenic mitigation projects is undertaken, so that the same mistakes are not repeated. By mobilising the organisations into joint action there will also be good opportunities for studying the health effects of Arsenic.

The Arsenic problem in Bangladesh is a nationwide problem with an expected estimation of 27 millions people exposed to high water Arsenic concentrations. When the guideline value in the future may be lowered to 10 µg/l then the exposed to population will be increased to 50 million. Therefore the solutions to be implemented should be sustainable.

There are two types of capacity buildings needed in the country:

- In the research & development field
- In the field work

In the research & development field:

As mentioned earlier there is a need of long term research & development on many topics. This work can be carried out at the universities of Bangladesh. As the situation is now there are some universities in Bangladesh like BUET, Dhaka University and Rajshahi University, involved in work on the Arsenic problem, but most of the researchers and publications are from outside of Bangladesh. To be able to carry out the research in Bangladesh based on the Bangladeshi resources, the universities in Bangladesh need to build their own their capacity. This may be accomplished through creating collaboration to Danish Universities on the various topics. For instance in the analysis of Arsenic; as mentioned earlier the measurement of Arsenic is a complicated process, so it is not enough to buy all the sophisticated instruments like AAS, but to develop methods, which are cost effective sensitive and precise. The inter-laboratory calibration showed that there are many laboratories in Bangladesh, but not all of them are equally good in measuring Arsenic. There are good examples of collaboration work at the University level in the LUCED<sup>2</sup> regime which the universities from Thailand, Malaysia, Southern Africa and Denmark are part of.

In the Field work:

There is a need for increasing the reliability of supplying Arsenic free drinking water. Developing and implementing a proper water supply requires adequately trained personnel in sufficient numbers. Monitoring of the drinking water quality with respect to Arsenic concentration is required for safeguarding the health except for most of the existing water supplies in the affected regions. Monitoring will also require trained personnel. This indicates that there is a need of educating people, who will be responsible for implementing and monitoring of the solutions. This type of

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<sup>2</sup> Linked University Consortia for Environmental and Development. See: [www.duced-iua.dk](http://www.duced-iua.dk)



capacity building can be achieved at the lower institutional levels as vocational training and technical diploma schools.

## CONCLUSIONS

- An estimated 27 million people in Bangladesh are currently exposed to water with toxic Arsenic concentrations above the national guideline of 50 µg/l
- Based on the existing literature there will probably be a need of revising the present Bangladesh guideline value for Arsenic in drinking water from 50 µg/l to a lower value. The guideline recommended by the WHO is set at 10 µg/l. This will increase the official number of excessively exposed persons to around 50 million, or more than a third of the population of the country.
- The available literature shows that people are also exposed to Arsenic through food products thus adding to the need of lowering the guideline for water. The quantitative importance is not yet established
- The available field test kits in Bangladesh are not reliable to analyse Arsenic concentrations at the required level of 50 µg/l and not at all at 10 µg/l.
- It is necessary to monitor both the shallow tube wells and deep tube wells with suitable intervals to assure that the Arsenic concentration is not increasing with time.
- Existing tube wells in Arsenic affected area should be tested for Arsenic before a decision on the future supply of Arsenic free drinking water is taken.
- The experience gained by various agencies on Arsenic mitigation shows that the alternative solutions like dug wells, pond sand filter and rainwater harvesting may be feasible, but not always successful. Therefore care must be taken when these solutions are offered as an option for Arsenic free drinking water. It is not advisable to offer these solutions on short term in the areas where there is no prior experience on use of these technologies.
- Community participation is important when any solution is offered, the decision of proper solutions should be taken by the community and not by the donor agency, to ensure the sustainability of the project.
- It is not enough to paint the tube wells red (as a warning) or green after screening the tube wells. It is also necessary to make sure that the consumers understand the purpose of the colouring.
- Education of the people is necessary to make them aware of the long term consequences of consuming Arsenic contaminated water, both for drinking and cooking purpose and make them aware of the possible ways of getting Arsenic free water.
- It is possible that already enough deep hand tube wells exists in the Arsenic contaminated area in the DANIDA intervention area and hence the need of installing more tube wells is low.
- The existing deep hand tube wells in an area should be analysed to see whether the deeper ground water is contaminated with Arsenic, or there is a possibility of saltwater intrusion in the coastal areas before attempting installation of new deep hand tube wells.
- The possibility of establishing piped water supply in the areas where an irrigation deep tube well exists may be evaluated.

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## **APPENDIX 1: TERMS OF REFERENCES FOR THIS CONSULTANCY**

### **Objective**

The objective of this consultancy is that a concise paper on the present state-of-the-art of Arsenic mitigation research in relation to drinking water supply in Bangladesh is available before the joint annual sector review in February 2003.

### **Output**

The short-term consultants will be expected to prepare a brief paper (20-30 pages) to be submitted to DANIDA before the 27<sup>th</sup> of January 2003 on the state-of-the-art of Arsenic mitigation research in relation to drinking water supply in Bangladesh, including hydro-geological issues, health issues, alternative water supply options, water cleaning techniques, and Bangladeshi policies/guidelines. The report may include recommendations, if appropriate, on possible changes of activities/strategies under the DANIDA funded Arsenic mitigation component. The report should also include a brief chapter on the possible bioaccumulation of Arsenic in the human food chain.

### **Scope of Services**

In order to achieve the above output, the scope of services of the consultants is expected to include the following:

- Desk study of all relevant available information and documentation on Arsenic mitigation research in the affected countries.

Study of documentation on DANIDA funded Arsenic mitigation activities and relevant policy documents/guidelines from Bangladeshi authorities.

## Appendix 2: Arsenic removal Technologies

The main principle of removing arsenic from water is by adsorption. The arsenic removal processes can be classified as following

1. Coagulation with metals salts
2. Adsorption on activated/coated surfaces
3. Ion-exchange
4. Membrane processes

### *Coagulation*

The main processes involved in arsenic removal by Coagulation consists in addition of metal salts(Coagulation), sedimentation and filtration. The removal mechanism of dissolved arsenic during coagulation with metal salts is through adsorption(association of the dissolved contaminant with the surface of the precipitate), occlusion(entrapment of adsorbed contaminants in the interior of the growing particle) and solid solution formation(incorporation of the contaminant in to the surface of the precipitate). And at high coagulant dosages, adsorption of inorganic contaminants to precipitated metal hydroxide solids is likely to be the predominant mechanism for contaminant removal.

The various coagulants that are described in the literature for their arsenic removal efficiency are presented here.

### *Iron & Alum coagulation:*

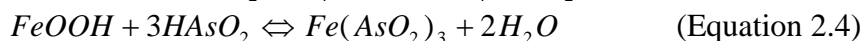
When Iron and aluminium salts are added to water under oxidising conditions their respective hydroxides are produced, and the amount of which depends on pH. Aluminium hydroxides /Cheng *et al.* 1996/ are produced in the pH range of 5-8 with least solubility at pH 6.2 and Iron hydroxides are produced in the pH range of 6-10 with least solubility at pH 8. According to /McNeill & Edwards 1995/ the concentration of particulate aluminium formed during coagulation increased 310 % when the coagulation pH was decreased to 6.8 from 7.4, which means that less particulate aluminium is present at higher pH. Isoelectric points from 6.6 to 7.3 for amorphous  $\text{Al}(\text{OH})_3(\text{s})$  have been reported. Isoelectric points from 6 to 8.6 have been reported for amorphous Iron hydroxide. /Ferguson & Anderson, 1978/.

Since the removal of Arsenic by Iron and aluminium is mainly due to adsorption the amount of Arsenic removed increases with the amount of aluminium or Iron hydroxide present in the water. Studies conducted by /Hering *et al.*, 1996/ showed that the removal of Arsenic by addition of  $\text{FeCl}_3$  was greater than by adding preformed Iron hydroxide indicating that adsorption along with coprecipitation is taking place.

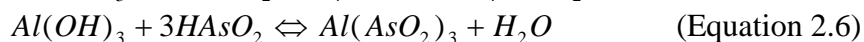
Literature studies indicate that better removals of Arsenic are achieved by Iron and aluminium in case of As(V) compared to As(III), but /Ferguson & Anderson 1978/ achieved better Arsenic removals in case of As(III) compared to As(V), and according to Yoshida *et. al.* similar removals

were obtained in both the cases using Iron coagulation. /Ferguson & Anderson 1978/ found a decrease in pH values in case of As(III) and the opposite occurred in case of As(V) during coagulation with Iron and Alum salts. In the absence of arsenic the precipitates showed no such drift. Removals of As(V) and As(III) during Iron (Equation 2.3 & 2.4) and alum coagulation (Equation 2.5 & 2.6) are explained by the following equations.

*Iron coagulation:*



*Aluminium coagulation:*



Better Arsenic removals are achieved in case of Iron coagulation compared to alum coagulation. Best removals of As(V) were achieved at pH of about 6-8 in case of Iron whereas in case of alum best removals were achieved below pH 7. In case of As(III) the rate of removal increased with pH until a pH of 9.

Greater removals can be achieved by using higher coagulant dosages. In a literature review by /Nilsson, et. al., 1994/ it was mentioned that a Fe(III)/As(V) ratio of 3 is generally considered sufficient for effective arsenic removal and dissolution of arsenic from precipitates is reported to decrease with an increasing Fe(III)/As(V) ratio.

*Lime softening:*

Lime precipitation is not only used to soften hard water but is also extensively used in the treatment of industrial wastewater to remove metals as precipitates by raising the pH with lime; precipitation of magnesium results in increased /McNeill & Edwards 1995/ removals. In the lime softening process, an appropriate amount of hydrated lime,  $Ca(OH)_2$  is added to soften hard water. Calcium Carbonate is a major component of the precipitate and if magnesium content as well as pH is sufficiently high (pH > 10.5), magnesium hydroxide is also formed.

Removal of Arsenic by lime softening was studied by /Sorg & Logsdon, 1978 and Logsdon; Dutta & Chaudhari, 1991; Kartinen & Christopher, 1995, 1995; McNeill & Edwards 1995/. The studies indicate that arsenic removal can be better achieved at pH above 10.5 and the removal decreases with decreasing pH below pH 10.5.

Better removal efficiencies are achieved for As(V) compared to As(III). Higher arsenic removals are achieved when  $Mg(OH)_2$  was precipitated compared to  $Ca(CO)_3$  at high pH (pH > 10.5). The amount of  $Ca(OH)_2$  to be added can be reduced by adding powdered coal and the removal efficiency can be increased.

Apart from the above conventional coagulatives, Basic Yttrium Carbonate was also



tested for its ability to remove Arsenic /Wasay *et al.* 1996/. The maximum removal of As(III) and As(V) was obtained in the pH range of 9.8-10.5 and 7.5-9. The removal was >99%. The removal of As(V) and As(III) are concentration dependent; as the concentration increases the removal decreases. Under neutral and acidic conditions. The isoelectric point of BYC is 7.5.

Removals of Arsenic during removal of Iron and manganese in water treatment plants is also reported by /Kartinen & Christopher, 1995; McNiell & Edwards, 1995/.

### *Adsorption on Activated/Coated surfaces*

#### Activated Alumina:

Activated alumina is granular aluminium oxide. It can be regenerated with diluted NaOH and sulphuric acid. According to /Ghosh & Yuan 1987/ the  $pH_{ZPC}$  of commercial Alumina is 7.89 and  $pH_{Zpc}$  values in the range of 7.4 to 8.6 have been reported.

Studies were conducted by /Ghosh & Yuan 1987; Jalil, 1997; Hathaway & Rubel, 1987; Jekel, 1994; Xu, *et. al.*, 1991; Ghosh & Yuan, 1987; Gupta & Chen, 1978; Kartinen & Christopher, 1995; Jekel, 1994/ on removal of Arsenic on activated alumina. These studies reported that the activated alumina can be used in removal of Arsenic with better removal efficiencies for As(V) compared to As(III) in the pH range of 3-8 /Xu *et al.*, 1991/. According to /Jalil, 1997/Activated alumina has an equilibrium capacity for As(III) upto 10 times less than that for As(V).

The best pH value for As(V) was 5.5 to 6, above this pH less removals are obtained. As observed for As(V) the adsorption of As(III) on alumina was also pH dependent with adsorption maxima at pH around 7 for As(III). The presence of high total dissolved decrease the Arsenic adsorption.

The % As(III) removal was greatly affected by the initial As(III) concentration, however As(V) removal was slightly affected by the initial concentration level. A decrease in % removal with increasing salinity was observed. In general, in comparison with As(V), As(III) removal efficiency was greatly affected by varying amounts of silica.

#### Activated Bauxite:

/Gupta & Chen 1978/ conducted experiments on removal of Arsenic by activated bauxite and found that Arsenic removal is greatly affected by the pH. The % As(III) removal was greatly affected by the initial As(III) concentration, however As(V) removal was slightly affected by the initial concentration level. >97% removals in case of As(V) in the concentration range of 1.85-7.8 mg/L were noticed at pH 6.5-6.8 in fresh water and % removal decreased with increasing salinity to 87% in sea water. >70-80% removals in case of As(III) in the concentration range of 0.49-2 mg/L were noticed at pH 7.8-7.9 in fresh water and % removal decreased with increasing salinity to 57% in sea water.

#### Activated Carbon:

/Gupta & Chen 1978/ conducted experiments on Arsenic removal by using Activated carbon and found that Arsenic removal is greatly affected by the pH. >83.5% As(V) removals were achieved in the concentration range of 0.1-2.6 mg/L at pH 6.8-6.9 in fresh water and % removal decreased

with increasing salinity to 62.6‰ in sea water. They found that the best Arsenic removal efficiencies were achieved by activated alumina, followed by Activated bauxite and carbon.

According to /Rajakovic & Mitrovic 1992/ Activated carbon has a poor adsorption capacity for Arsenic, but the adsorption capacity can be improved by chemisorption. When activated carbon was activated with chemical agents the removing effect of As(III) was improved: slightly with  $\text{Ag}^{2+}$  ions but significantly with  $\text{Cu}^{2+}$  ions. A method of pretreating an activated carbon by a ferrous salt could increase the carbon capacity of As(V) removal by a factor of 10, due primarily to adsorption of  $\text{Fe}^{2+}$  and formation of  $\text{Fe}^{2+}$ -arsenate complexes. /Jekel, 1994/.

#### Coral limestone coated with Fe(III) or Aluminium hydroxide:

/Ohki et al. 1996/ conducted experiments to test the adsorption ability of Coral lime stone coated with Ferric and Aluminium hydroxide and found that the Aluminium loaded coral lime stone has a higher adsorption ability than Fe(III) hydroxide loaded coral lime stones, especially at low As(V) concentrations with adsorption of As(III) being less compared to As(V). The adsorption of As(III) was independent of pH in the pH range of 3-11, while the adsorption of As(V) was independent of pH in the pH range of 2-11.

#### Iron oxide coated sand:

/Joshi & chaudhari, 1996/ tested the possibility of Arsenic removal by using Iron oxide coated sand and found that this can be used for removal of Arsenic. He found that removal of As(V) is better than removal of As(III).

#### Removal by Hematite(80.8% $\text{Fe}_2\text{O}_3$ ):

/Singh et al. 1988/ carried out tests on adsorption of As(III) on hematite in the concentration range of 1-10 mg/L at 1 g/L of hematite. The maximum removal at saturation was found to be 96% at 1 mg/L of As(III) and pH 7 and the uptake was purely concentration dependent and increases with the initial concentration of As(III).

According to /Xu et. al. 1991/ the amount of As(V) adsorbed by hematite increased with pH to a maximum at pH around 6 and then decreased with an increase in pH. PH(ZPC) of variety of Hematite is in the range of 6.5-7.

Apart from the above mentioned activated/coated surfaces Bone char /Jekel 1994/ and clay minerals Kaolinite and Montmorillonite /Jekel 1994/ were also tested for their Arsenic removal ability. Bone char can be used for Arsenic removal, but after exhaustion, the char could not be regenerated and had to be disposed of. The bone char probably contained ferric oxide, which would be responsible for the adsorptive removal. The adsorption of Arsenic on Kaolinite and Montmorillonite depends on pH and the type of Arsenic species present /Frost & Griffin 1977/.

#### Granular Ferric Hydroxide:

Granular Ferric Hydroxide has also an high affinity for Arsenic (Driehaus W. 1998) and some treatment units have been installed in West Bengal, India for removal of Arsenic.

## *Membrane processes*

The principle of membrane process is that water is allowed to pass through special filter media, which physically retain the impurities present in the water. Reverse Osmosis, Electrodialysis and Colloidal floatation are some of the membrane processes studied

Reverse Osmosis: /Kartinen & Christopher, 1995/ reported that reverse osmosis is more effective in removing As(V) than As(III). As(III) removal rates of 40-80% and As(V) removal rates of >97% have been reported literature.

Electrodialysis: Electrodialysis is also more effective in removing As(V) than As(III). As(V) removal of more than 95% have been reported in the literature. However the available literature on electrodialysis is very limited /Kartinen & Christopher, 1995/.

Colloidal flotation: /Peng & Di, 1994/ showed that colloid flotation can be used to remove Arsenic and foreign ions  $\text{SO}_4^{2-}$  and  $\text{PO}_4^{3-}$  have an inhibiting effect on the removal of arsenic.

## *Ion exchange*

The principle of Ion exchange is that Arsenic is adsorbed on to resins in exchange of other ions that are less strongly adsorbed compared to Arsenic. Ion exchange method is also tested for removal of Arsenic. Due to its different dissociation equilibria, only pentavalent arsenic will be present as an anion with one or two charges in the medium pH range and can be exchanged in resins. Different ion exchange resins were tested for their ability of Arsenic removal. Better As(V) removals are achieved compared to As(III). /Jekel 1994; Kartinen & Christopher, 1995; Matsunga, et al. 1996; Hathaway & Rubel 1987; Shen 1973/.

The advantages and disadvantages of the above mentioned Arsenic removal Technologies are summarised in Table 1.

Removal Technology	Advantages	Disadvantages
Coagulation	<ul style="list-style-type: none"> <li>• Low Capital Costs</li> <li>• Simple chemicals</li> <li>• Already exists at many treatment plants</li> </ul>	<ul style="list-style-type: none"> <li>• Requirement of Several Chemicals</li> <li>• Problems with Sludge disposal</li> <li>• Maintaining of Filters</li> <li>• Low Removal Efficiency</li> <li>• Re-adjustment of pH is some times required</li> <li>• Pre-oxidation of As(III) is necessary to improve the removal efficiency and reduce the coagulant dosage.</li> </ul>
Adsorption on Activated/Coated Surfaces	<ul style="list-style-type: none"> <li>• No daily sludge problem</li> <li>• No solid waste</li> </ul>	<ul style="list-style-type: none"> <li>• Few Chemicals needed for regeneration and periodic regeneration of filter material.</li> <li>• Requires monitoring of breakthrough</li> <li>• Readjustment of pH</li> <li>• Toxic Liquid Waste</li> <li>• Requires trained person for maintenance</li> <li>• High Capital cost</li> </ul>
Membrane Processes	<ul style="list-style-type: none"> <li>• High removal efficiency</li> <li>• No Solid waste</li> <li>• No chemical requirements</li> </ul>	<ul style="list-style-type: none"> <li>• High Capital Cost</li> <li>• High Running Costs</li> <li>• Qualified persons for maintenance</li> <li>• Toxic Liquid Waste</li> <li>• Re-adjustment of water quality is required</li> <li>• Pre-oxidation of As(III) is necessary</li> </ul>
Ion-Exchange Methods	<ul style="list-style-type: none"> <li>• No solid Waste</li> <li>• High removal efficiency</li> <li>• No chemical requirements</li> <li>• No need of pre-oxidation of As(III)</li> </ul>	<ul style="list-style-type: none"> <li>• Toxic liquid waste</li> <li>• High Capital Cost</li> <li>• Qualified persons for maintenance</li> <li>•</li> </ul>

**Table 1.** Advantages and Disadvantages of the different Arsenic removal Principles.

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### Appendix 3: Evaluation of Treatment Technologies:

Type of Option	Principle	Name of the filter	Capital Cost	Maintenance cost	Feasibility
Individual households	Coagulation/Coprecipitation	DPHE-DANIDA Bucket Treatment Unit	1	1	1
		Improved DPHE-DANIDA Bucket Treatment Unit	1	1	1
		Steven's Institute Technology.	2	1	1
		Garnet Filter BCSIR Filter unit	2	1	1
		Passive sedimentation	1	1	1
		SORAS	1	1	1
	Adsorption onto Activated/Coated surfaces	Alcan Enhanced Activated Alumina filter (MAGC)	2	2	2
		BUET Activated Alumina Filter	2	2	1
		BUET Iron coated Sand	2	2	1
		ARU of Project Earth Industries inc., USA	2	2	2
	Ion Exchange:	Tetrahedron	3	2	2
	Membrane Process	MRT-1000	3	3	3
		Reid System	3	3	3
		Techno-food	3	3	3
		Reverse osmosis and bicycle pump.	3	3	3
	Indigenous:	Sono 3-kolshi Filter:	1	1	1

Type of Option	Principle	Name of the filter	Capital Cost	Maintenance cost	Feasibility
		Shapla filter:	1	1	1
		Chari filter	1	1	1
		Shafi Filter	2	1	1
		Adarsh Filter	2	1	1
	Rain Water Harvesting		3	1	1
Community	Coagulation/coprecipitation:	Iron Removal Plant:	2	1	1
		AIHH&H	2	1	1
		Fill & Draw Unit	2	1	1
	Adsorption onto Activated/Coated surfaces	Oxide India Technologies	3	2	1
		Adhiacon:	3	2	1
		Alcan Enhanced Activated Alumina filter	3	2	2
		AdsorpAs:	3	3	1
		PHED	2	2	1
		Aqua Bind	3	2	1
		School of Fundamental research	2	2	1
	Ion Exchange:	Ionochem	2	2	1
		Water Systems International.	2	2	1
		Tetrahedron	3	2	1
		Insitu Arsenic immobilization	3	2	2
	Deep Hand Tube well		2	1	1
	Pond Sand Filter		1	1	1
	Dugwell		2	1	1
Village level	Piped Water Supply		3	1	3

Capital cost per family: 1 = < 500 Tk; 2 = 500-1000 Tk; 3 = > 1000 Tk

Maintenance cost per family: 1 = < 100 Tk/ year; 2 = 100-500 Tk/year; 3 = > 500 Tk/ year

Feasibility: 1 = very (Simple in operation, locally available material, no Use of Electricity)

2 = average (Simple in operation, material to be imported, no Use of Electricity)

3 = difficult (special skills, material to be imported, Use of Electricity)

## Appendix 4: Cost analysis of Field kits Vs Laboratory method.

An attempt was made here to calculate the costs involved in measuring Arsenic using the field kits and AAS.

### *Analysis by Field test Kit:*

It was estimated (*Ahmed F. 2002*) that by assuming that 7.5 million tube wells have to be tested and the cost of one test kit is 2500 (with an effective capacity of 80), it would cost **234 million Tk** for screening all the Tube wells. This is the only the cost of the chemicals and procurement of the field kits. The labour cost is not included.

One test with a Field test kit takes from 20-40 minutes depending on the type of Kit used. The Merck kit takes 30 minutes for one analysis. If we assume that a person works effectively 7 hours a day and there is no transportation time then the number of the samples that can be measured per day are: 14. By employing 1000 field workers around 14000 samples can be measured per day, and it will take around 540 days to screen the 7.5 million tube wells. To analyse an equal number of samples by AAS per day around 70 AAS are required.

(School of Environmental Engineering)

The Capital cost of establishing 70 AAS is: 224million Tk. (assuming 3.2 million Tk for each AAS)

The cost of the chemicals to measure 7.5 million tube wells would be:

The monthly cost of the chemicals for the analysis of 200 samples per day is 12,000 Rs.

That is to analyse 7.5 million samples the cost would be: 14.7 million Rs.

The total cost for the analysis of 7.5 million samples including the capital cost of the AAS would be: **239 Tk.**

The cost of the labour is not included.

The above calculations for analysis using AAS are based on the information from the rapport on Field Testing Kits for Arsenic: How effective are the million Dollar projects.(1999) by School of Environmental Studies, Jadavpur University Calcutta. India, and the costs are from 1999, therefore the new costs can be higher.

### **Litterature:**

Ahmed M. F. Alternative Water supply options for arsenic affected Areas of Bangladesh. (A theme paper for discussion). International Workshop on Arsenic Mitigation in Bangladesh Dhaka, 14-16<sup>th</sup> January, 2002

Field Testing Kits for Arsenic: How effective are the million Dollar projects.(1999). School of Environmental Studies, Jadavpur University Calcutta. India.



## Appendix 5: List of Field Test Kits

Test kit	Principle	Analysis	Interference	Min DL µg/l	Producer	Remarks
Merck kit	Mercury bromide	Semi quantitative	Sulfide (1-10 mg/L)	100	Germany	Widely used
Merck kit (improved version)	Mercury bromide	Semi quantitative	Sulfide (1-10 mg/L)	10	Germany	Widely used
AAN	Mercury bromide	Semi quantitative	Sulfide (0.1 mg/L)	20	Japan	Widely used
NIPSOM	Mercury bromide	Semi quantitative	Sulfide (0.1 mg/L)	20	Bangladesh	Widely used
AIH&PH	Mercury bromide	Yes/No	Sulfide (1-10 mg/L)	50	India	Widely used
Aqua	Mercury bromide	Yes/No	Sulfide (1-10 mg/L)	50	India	Widely used
Arsenic Kit from Hyderabad ; India	Secret	Quantitative	Don't mention	10	India	New in the market
HACH 5-stage		Semi qualitative			USA	
Hach EZkit	Same as mercury bromide	Semi qualitative	Possibility of removing the interference	20	USA	Widely used
Arsenator (PeCo75)	Don't know	Semi qualitative, but possibility of quantitative		2.5	Austria	Is been used
Apyron kit		Semi qualitative		5	US	New in the market
NCL kit	Borohydride	Quantitative (possibility of speciation)		5	India	Not available commercially
AsTOP	Generation of arsen	Semi qualitative		10	US	New in the market
Biotest	Bacteria	Quantitative (Possibility of speciation)		5	US	New in the market
GPL field test kit	Based on the AAN kit and 2 additional steps			20	Bangladesh	
ITS low range Arsenic Check		Semiquantitative	Sulfide interference is removed	2	US	New in the market
Arsenic quick test kit (ITS)		Semiquantitative	Sulfide interference is removed	5	US	New in the market

## Appendix 6: DANIDA and Bangladesh Activities.

DPHE-DANIDA Arsenic Mitigation pilot project was implemented (March 1999-March 2001) by the Department of Public Health Engineering with assistance from DANIDA Advisory Group with the following objectives:

- Formulate and define a future strategy for Arsenic and Arsenic components in DANIDA's Sector Programme support for Water supply and Sanitation
- Identify areas of cooperation and define responsibilities for respectively DANIDA and World Bank in DANIDA areas
- Identify and test technical solutions for Arsenic mitigation.

The pilot project covered Chaumohani (Noakhali) and Laksmipur (Laksmipur) pourashavas where about 5600 hand tube wells (800 DANIDA hand tube wells and 4500 hand tube wells) were tested for Arsenic and a GIS database was established. 95% of the Hand Tube wells were found to be contaminated with Arsenic. The DANIDA installed handtube wells were tested at field level using the Merck test kit and at the Laboratory of Noakhali. The body of the DANIDA installed tube wells were painted purple and red spout for Arsenic indication.

The survey showed that 94% of the people used water from tube well for drinking puposes and the rest used piped water supply, deep hand tube wells for drinking in DPHE-DANIDA intervention areas. For cooking, washing and bathing purpose the majority prefers pond water. Based on the laboratory results 95% of the HTWs were found Arsenic contaminated in both the pourashavas. The daily water requirement for only drinking water per day per household varies between 21-40 liters.

The technology options tested under the AMPP are:

- Bucket Treatment unit (BTU),
- Fill and Draw unit (F&D)
- Underground sedimentation and Adsorption system
- Arsenic removal through IRU
- Arsenic Removal Unit
- Rain water harvesting
- 3- Kolshi System
- Passive Sedimentation
- Mini piped water supply system based on the deep tube wells.

Passive sedimentation, IRU and Arsenic Removal unit did not show effective removal of Arsenic. The 3-Kolshi system was also clogged within 2 weeks. Rainwater harvesting was planned for the use of single families, but neighbourhood families also shared the system, and the storage tanks became dry before the intended use. The mini piped water supply system is based on the Deep tube well water.

A total number of 4,300 families were supported with alternative mitigation options of bucket treatment units (BTU). 30 F&D units were installed. The BTU and Fill & Draw units served 22,556 beneficiaries. Capacity building and awareness development activities carried out in the form of project orientation workshops, training courses for the local level staff, urban elites, local

entrepreneurs, NGO leaders and caretakers. At users level courtyard meetings, posters, stickers, calendars, audiocassettes were used for hygiene promotion. The study carried out by the project on BTU showed that 75.56% of the people were using treated water for drinking and cooking.

The main alternatives identified under the AMPP for mitigating the Arsenic problem at different level are:

- BTU as short-term mitigation option for Arsenic mitigation at household level
- F&D unit as long-term mitigation option for community level, particularly at institutions
- DHTW as the long-term option at community level
- Mini piped water schemes as long-term option at community level
- Rainwater harvesting as supplementary option at household level

To supply Arsenic free drinking water within the areas covered by the DANIDA supported Urban and Rural water supply and sanitation components (WSS) the Arsenic Mitigation Component was established. The starting date for the component was 1<sup>st</sup> January 2001 with duration of 3½ years. In accordance with GOB strategy, main emphasis will initially be given to Arsenic mitigation to rural areas. Arsenic mitigation component will address Arsenic mitigation in 11 upazila (these upazilas are identified as the areas where more than 75% of the tube wells contain an Arsenic concentration of above 50 µg/l) under rural water supply and sanitation components and a number of Purashavas, Upazila centers and growth centers of ongoing urban water supply and sanitation components. The main technical input will be the establishment of 6000 Deep hand tube wells to serve the worst affected villages in the 11 upazilas.

The Arsenic mitigation will comprise a sequence of:

- Planning, strategy development and preparation of implementation manuals
- Baseline surveys, including screening of tube wells
- Promotional activities
- Provision of Arsenic mitigation options

The implementation will be phased as follows:

- Implementation of a 6 months inception phase without hardware implementation, and with the preparation of an inception report after 5 months
- Pilot implementation of 3 entirely contaminated thanas
- Implementation in 8 heavily contaminated thanas
- Implementation in entirely or heavily contaminated pourshavas, thana centres and growth centers

In parallel to the above sequence, the AMC will build up co-operation with other stakeholders in researching and developing suitable means of mitigation options considering the local situation within the AMC area.

All tube wells will be screened. To the extent practical, public tube wells will be screened first followed by private tube wells. Considerable emphasis will be given to provision of reliable data, through the use of the high quality testing equipment and proper quality control. The screening will not be initiated in an area before Arsenic mitigation, short term or long term, can be offered to at least the worst affected part of the population.

The following have been achieved by the end of June 2002.

- Identification of the worst affected villages completed
- 150 DHTWs established by June 2001 in each of the three worst affected upazilas
- An average of 150 DHTWs established per GOB financial year in each of the 11 thanas during the period of July 2001 to June 2004
- Network of production and sales outlets for household's treatment options promoted to all families and subsidized household treatment units distributed to the very poor families
- Three household Treatment options promoted to all families and subsidized household treatment units distributed to the very poor families.

DANIDA has undertaken a program to test about 130,000 estimated TWs in the whole operational areas under Arsenic mitigation component and until so far 72,625 TWs were screened using MERK test kit. All the screened TWs have been marked with red or green colour as per the water quality (60% red & 40% green).

#### Bangladesh Activities:

To combat the Arsenic situation in Bangladesh, the government of Bangladesh has taken following initiatives:

- Bangladesh Arsenic Mitigation Water Supply Project ((BAMWSP):

BAMWSP is a 4-year project launched in 1998 by Department of Public Health and Engineering of the Local Government Division under Ministry of Local Government, Rural Development, and Cooperatives. The principle components of the project are:

- Improved understanding of the Arsenic problem through national survey
  - Strengthening implementation capacity of the Local Govt. entities and community based organisations and community based organisations
  - Onsite mitigation through sub-project development jointly by LGE and Community based organisations.
  - Development of an Arsenic database.
- National Arsenic Mitigation Program (NAMP):
- The Government of Bangladesh is in the process of establishing an Arsenic Policy Support Unit (APSU) in the local Government Division to prepare and implement NAMP.

The role of Arsenic policy support Unit (APSU) in Arsenic mitigation is:

- Assist in the formulation of Government policy and strategy on Arsenic related issues.
  - Facilitate/coordinate relevant ministries/agencies to address the Arsenic crisis.
  - Monitoring, evaluation and reporting.
- Water Development Board:
- Water Development board under the ministry of water resources has been working on geological investigations for Arsenic in different parts of the country.

## Appendix 7: Arsenic contamination in the Danida Intervention area

Arsenic concentration in the shallow and deep hand tube wells in the areas under DANIDA. > 50 µg/l are the tube wells where the measured Arsenic concentration is > 50 µg/l, and > 10 µg/l are the tubewells where the measured Arsenic concentration is >10 µg/l, which means that these tube wells also includes the tubewells with Arsenic concentrations > 50 µg/l.

DISTRICT	THANA	Deep Tubewells <sup>3</sup>					Shallow Tubewells <sup>3</sup>					DANIDA Report <sup>4</sup>		
		Tested Total	> 50 µg/l		> 10 µg/l		Tested Total	> 50 µg/l		> 10 µg/l		BGS %	ASS %	DPHE %
			No.	%	No.	%		No.	%	No.	%			
Barguna	Amtali	7	0	0	0	0	0							
	Bamna	5	0	0	0	0	1	0	0	0	0			
	Barguna Sadar	9	0	0	0	0	0							
	Betagi	4	0	0	0	0	1	0	0	0	0			
	Patharghata	4	0	0	0	0	1	0	0	1	100			
Barisal	Bakerganj	7	0	0	0	0	2	1	50	2	100	50	75	50
	Banaripara	4	0	0	1	25	4	2	50	4	100	50	75	70
	Barisal Sadar	7	1	14	2	28	6	4	67	0	0	57	75	50
	Ujirpur	-	-	-	-	-	-	-	-	-	-		78	70
Feni	Sonagazi	1	0	0	0	0	9	7	78	9	100	78	80	50
Jhalakati	Kathalia	6	0	0	0	0	3	0	0	0	0	0	10	
Lakshmipur	Ramgati	1	0	0	0	0	8	3	38	7	88	40	75	60
Lakshmipur	Lakshmipur Sadar	3	0	0	0*	0	7	3	43	6	86	50	100	91
Lakshmipur	Raipur (L)	1	0	0	0*	0	6	6	100	6	100	100	100	91
Noakhali	Begumganj	1	0	0	0*	0	11	11	100	11	100	100	100	75
Noakhali	Companiganj (N)	2	0	0	0*	0	7	2	29	4	57	30	50	8
Noakhali	Noakhali Sadar	1	0	0	0	0	10	6	60	2	20	50	75	53
Noakhali	Hatiya	-	-	-	-	-	-	-	-	-	-	-	-	-
Patuakhali	Bauphal	8	0	0	0	0	0							
Patuakhali	Dashmina	6	0	0	0	0	0							
Patuakhali	Galachipa	4	0	0	0	0	0							
Patuakhali	Kalapara	7	0	0	1	14	1	0	0	1	100			
Patuakhali	Mirzaganj	6	0	0	0	0	0							
Patuakhali	Patuakhali Sadar	8	0	0	0	0	2	0	0	1	50			
Pirojpur	Bhandaria	2	0	0	0	0	4	0	0			0	10	0
Pirojpur	Mathbaria	1	0	0	0	0	7	1	14	1	14	15	20	0
Pirojpur	Pirojpur Sadar	1	0	0	0	0	6	1	17	3	50	33	75	75
Pirojpur	Sarupkhati	-	-	-	-	-	-	-	-	-	-	-	10	0

\* means that some of the deep hand tubewells have arsenic cocentration close to 10 µg/l.

<sup>3</sup> From DPHE-BGS-2001. [www.bgs.ac.com](http://www.bgs.ac.com)

<sup>4</sup> Sector Programme Support Component Description Arsenic Mitigation Component Bangladesh. Ref. N0. 104.Bang.814-7, July 2000.